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CLAUDIAN AQUEDUCT (ROME), BUILT IN 50 A.D. (*Frontispiece.*)

WATER-SUPPLY.

(CONSIDERED PRINCIPALLY FROM A SANITARY STANDPOINT.)

BY

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PREFACE.

Compilation must of necessity enter largely into an undertaking such as the present; and disconnected tabulations, together with frequent references to the findings of other investigators, naturally form no small portion of the body of the text. The writer hopes and believes that full acknowledgment has been given whenever material has been extracted, from either the published works or private notes of other authors, and he trusts that the contrast may not be considered too vivid between such extracts and the humbler record of his own inquiries. It is hoped that this book may prove of interest to several classes of men, quite widely separated in tastes and occupations: to the physician, who wishes to keep in touch with this particular phase of sanitary science, but whose time does not permit of his undertaking such investigation personally; to the hydraulic engineer, whose professional duties prevent his sifting out from the mass of recent bacteriological and chemical results such facts as bear upon his specialty; to the water-analyst, or the chemical student, who may seek to employ analytical methods widely used, and largely based upon the report of the committee of the American Association for Advancement of Science; and, finally, to the general reader who, as a water consumer, feels a natural interest in the continually recurring water problem of the day.

The writer is under obligations to so many persons, both here and in Europe, for courtesies extended and information furnished, that it is quite hopeless to properly enumerate them here; but he desires to express his especial indebtedness to the *Engineering News* for its kind assistance in securing a number of the illustrations.

WILLIAM P. MASON.

RENSSELAER POLYTECHNIC INSTITUTE,
TROY, N. Y., February, 1896.

CONTENTS.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

APPENDIX.

WATER-SUPPLY.

CHAPTER I.

INTRODUCTORY.

FROM remote antiquity the highest value has been set upon an abundant and pure water-supply. Centres of population sprang up in ancient times around those points where it was readily available, and great expenditures, of labor and treasure, were made to carry it to places where it was not naturally plenty. Not only was a generous daily *per capita* allowance sought for, but we note in the centuries gone by unmistakable evidences of a keen appreciation of the dangers lurking in a polluted supply; and upon this point many of the ignorant consumers of our own day and generation would be benefited did they consult the wisdom of the past.

Hippocrates, who wrote upon the value of pure water some four hundred years before the beginning of our era, advised boiling and filtering a polluted water before using it for drinking,—advice which all must consider entirely "up to date."

He further believed that the consumption of swamp-water, in the raw state, produced enlargement of the spleen.

Pliny (A.D. 70) in his "Natural History" (book XXXI., chapters I. to VI.) devotes large space to the discussion of potable water, and thus speaks of one of the numerous supplies of Rome, which, by the way, is a water in use to-day:

"Among the blessings conferred on the city by the bounty of the gods is the water of the Marcia, the cleanest

of all the waters in the world, distinguished for coolness and salubrity."

Libavius in 1595 refers to Pliny's work, and adds the curious suggestion that the weight of a water is proportionate to its potability.

During the Middle Ages it was observed that water sometimes became poisonous through being distributed in lead pipes.

Although Lascaris, who died in 1493, did not recognize the power of water to intensify and spread certain epidemics, it is interesting to observe that his teachings upon the origin of disease came very near the germ theory of the present day.

Much the larger undertakings connected with ancient water-supply were those built entirely for, or at least in connection with, general systems of irrigation. "The extent of some of these great hydraulic works can be conjectured from the ruins remaining. Lake Maeris, in Egypt, was constructed at least 2000 years before Christ. Its dimensions were sufficient to regulate the annual inundation of the Nile, receiving the surplus waters when there was danger of a flood, and supplying the needed deficiency when the river reached a stage which would not irrigate the crops. This, with other large reservoirs of flood-waters, enabled a population of 20,000,000 to exist in the valley of the Nile, while it now supports barely one fourth of the number.

"In ancient times the valleys of the Euphrates and Tigris, now almost a desert, were densely populated. Four thousand years ago the rulers of Assyria had converted those sterile plains and valleys into gardens of extreme productiveness by the construction of immense artificial lakes for the conservation of the flood-waters of the rivers, and great distributing-canals for irrigation. One of these canals, supplied by the Tigris, was over 400 miles long and from 200 to 400

feet broad, with sufficient depth for the navigation of the vessels of that time.*

"In India tanks, reservoirs, and irrigating-canals were constructed many centuries before the Christian era, and a great part of that country was kept in the highest state of cultivation. Some of the tanks or artificial lakes covered many square miles, and were often fifty feet in depth.

"Evidences exist in New Mexico and Arizona that in prehistoric times a race now extinct had extensive irrigation-works and cultivated large areas." (Wyckoff.)

Professor F. H. Cushing advises the author of his discovery of ancient reservoirs of large size in southern Arizona.

Lake Maeris, above spoken of, is described by Herodotus as 413 miles in circumference and 300 feet deep. More modern travellers place the circumference at 50 miles. It is said to have been constructed 2084 B.C., and to have been connected with the Nile by a canal 12 miles long and 50 feet broad.

On the site of ancient Carthage there are still to be seen the great cisterns for storage of water, eighteen in number, and each about one hundred feet long, twenty feet wide, and nearly twenty feet deep. They were originally covered with earth, and to-day are in marvellously good repair. They lie in two long rows and empty into a common gallery situated between the rows. They belonged to the ancient or Punic city.†

"Drinking-water was supplied to ancient Carthage, from a spring 60 miles distant from the city, by means of a conduit, which in its course cut through mountains by tunnels and crossed valleys by lofty and massive aqueducts, in one instance 125 feet high. This conduit was four feet wide and

* The Nahrawan Canal. It is of great antiquity, and its former importance is shown by the ruins situated along its course.

† See "Carthage and Carthaginians," by Bosworth Smith.

six feet high, was covered throughout, and was constructed most substantially of masonry lined internally with cement." *

"Amongst the wonderful monuments of the former greatness of the Singhalese people must be mentioned the ruined tanks, with which scarcely anything of a similar kind, whether ancient or modern, can be compared. Thirty colossal reservoirs, and about seven hundred smaller tanks, still exist, though for the most part in ruins. In February, 1888, the largest and most important tank in Ceylon, that of Kalawewa, was, after four years of labor, completely restored. It was built 460 A.D. to supply Anuradhapura with water, but has been ruinous for centuries. Now again it contains an area of seven square miles of water, twenty feet deep, and supplies smaller tanks more than fifty miles distant." †

When we reflect that these great works of antiquity were accomplished without the aid of steam, electricity, or explosives, we are impressed with the belief that, in intelligent perseverance at least, "there were giants in those days." Our respect does not lessen when we contemplate the extent of the supply of water poured into the "Eternal City."

The following is freely taken from Forbes' lecture on the Roman aqueducts:

ROMAN AQUEDUCTS, ARRANGED IN CHRONOLOGICAL ORDER.

	Date of Construction.		Length.	
Appia	312	B.C.	11	miles
Anio Vetus	272	"	43	"
Marcia	145	"	61	"
Herculea branch	—		3	"
Tepula	126	"	13	"
Julia	34	"	15	"
Virgo	21	"	14	"
Augusta	10	A.D.	6	"

* 52d Congress, Sen. Doc. 41, Part. I, page 430.

† Chambers's Encyclopædia, III. 80.

	Date of Construction.		Length.	
Alsietina..............	10	"	22	"
Claudia................	50	"	46	"
Anio Novus	52	"	58	"
Neronian branch.......	97	"	2	"
Traiana................	109 to 200	"	42	"
Hadriana..............	117 to 1585	"	15	"
Aurelia................	162	"	16	"
Severiana..............	200	"	10	"
Antoniniana branch.....	215	"	3	"
Sabina—Augusta......	130 to 300	"	15	"
Alexandrina	226	"	15	"

(The miles above given are Roman, of 4854 feet. The entire length of the aqueducts in English miles would be 381.)

It has been calculated that, altogether, the supply was 332,306,624 gallons daily, which would have been over 332 gallons *per capita* upon a basis of a population of one million.

Notwithstanding that some of these aqueducts were damaged during the wars of the sixth and seventh centuries, the supply did not entirely cease until the fourteenth century, when Rome was abandoned by the papal court. In the present day four of the ancient sources still supply the city with water.

Of the imposing lines of arches which stalk across the Campagna none is more interesting than the stately Claudian aqueduct. (See frontispiece.)

Speaking of it, Pliny says: "The preceding aqueducts have all been surpassed by the costly work more recently commenced by the Emperor Caius and completed by Claudius. The sum expended on these works was 350,000,000 of sesterces." *

Near the city the Claudian arches were filled up by Aurelian, and made to do duty as part of the city wall, the

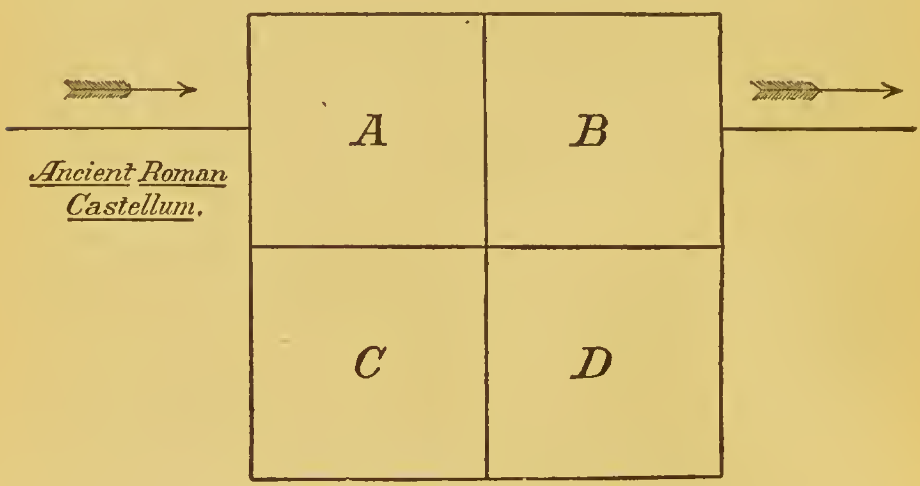
* About 12,700,000 dollars.

great gateway permitting passage at this point being known as the Porta Maggiore.

It is curious to observe that waters from different sources were carried in separate channelways upon the same arches.

Speaking of the Marcia, Tepula, and Julia waters, Frontinus says: "The three are carried on the same arcade, the highest being the Julia, then the Tepula, and lowest the Marcia." Near the Porta Maggiore the three channels are still distinctly to be seen.

It remains to say a word about the "castella" so often found along the courses of the Roman aqueducts. Forbes calls them "filtering-places," but such they could not have been—at least in the modern acceptation of the expression. They varied in size and in the number of their chambers, some having but four, while others numbered as many as twelve, compartments. One of the smallest size is here illustrated:



Ancient Roman Castellum.

The water entered chamber *A* and passed by means of holes in the floor into *C*, thence through openings in the wall into *D*, from which it rose through holes in the floor into *B*, and then passed on to Rome. A breaking of undue "head" would take place in the "castellum," as is accom-

plished in a more modern fashion at Vienna to-day; * but the real benefit derived from the construction of these chambers was probably the opportunity given for sedimentation.

Thus Frontinus says: "At the seventh mile, on the Via Latina, the Marcia, Tepula, and Julia are taken into a covered 'filtering-place,' where, as though breathing again after their course, they deposit mud."

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* At Vienna the aqueduct has a fall of 11,000 feet in the first 10 miles, and 10 feet per mile the balance of the way. It is about 60 miles long. The "head" is throttled by gates, every 100 feet of fall on the upper section. See *Engineering News*, Nov. 29, 1894.

CHAPTER II.

DRINKING-WATER AND DISEASE.

In that excellent treatise upon "Water-supplies and Inland Waters," issued by the Massachusetts State Board of Health, waters are classified as "normal" and "polluted," the former being such as are free from addition, directly or indirectly, of either sewage or industrial waste.

The relation of "normal" waters, as a class, to sanitary science constitutes a subject by itself, and one shrouded in much confessed ignorance and conflicting testimony, as is instanced by the doubt we entertain of the effect of "peaty water" upon the human organism.

Bog-waters in Ireland, especially those of Lough Sheighs in the county of Cavan, and of Lough Neagh, have long been used for the treatment of skin-diseases. The mineral waters of Askern, in Yorkshire, England, are about saturated with peaty material from the neighboring bogs, and have for many years been successfully used in the treatment of chronic rheumatism and skin-diseases.

Bothamley thinks it not improbable that the dissolved peaty matter is the curative agent in these waters.*

The water supplying the town of Mount Holly, N. J., is pumped from Rancocus Creek, and is at all times colored dark brown by dissolved peaty matter derived from a cedar swamp. It has never been known to produce gastric troubles, and the inhabitants think highly of it. An analysis by Prof. A. R. Leeds shows it to contain, in parts per million: †

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* J. Chem. Soc. lxiii. 696. † A. A. A. S. xxxvi. 128.

Free ammonia	.060
Albuminoid ammonia	.155
Required oxygen	5.500

It is true that a typhoid epidemic was traced to the use of this water, but it was shown to have been an instance of specific pollution, in no way connected with the peaty character of the town supply.

"Certain affluents of the Orinoco and Amazon have what is called black waters (*aquas negras*). When seen in mass, they are of a coffee-brown or of a greenish black. In the shade they are almost black, but in a glass they are brownish yellow, though very transparent. They have no disagreeable taste, and are preferred for drinking.

The samples analyzed contain, in parts per million, 28 of humic compounds, 1 of lime, 16 of total solids, and no nitrates. The residue contained silica, alumina, iron, manganese, and potassium. The waters do not undergo any chemical change on keeping." *

This ability to "keep well" is very frequently observed in brown waters, but it is by no means universal, nor does it seem to be a necessary characteristic indicating potability, for certain swamp-waters in which changes do occur during storage—notably that of the Dismal Swamp of Virginia—are held in esteem by sailors for use at sea after the "working" has been completed.

In writing to the author regarding this latter water Surgeon-General J. R. Tryon, of the U. S. Navy, says:

"I beg to enclose herewith copy of analysis made of Lake Drummond (Dismal Swamp) water in October, 1891, at the Naval Museum of Hygiene.

"This has always been considered a very pure water, and before the general adoption of condensers was much used

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* *Chem. News*, lviii. 305.

for naval vessels. The bureau has no special data bearing upon the relation to disease with the use of the class of waters referred to."

CHEMICAL EXAMINATION.

(Expressed in Parts per Million.)

Color	Yellow
Odor	Sweetish
Turbidity	None
Sediment	Very slight
Residue on evaporation	294.0
Loss on ignition	258.0
Fixed solids	36.0
Free ammonia	.016
Albuminoid ammonia	1.75
Nitrogen as nitrites	None
Nitrogen as nitrates	5.00
Chlorine	1.50
Hardness	49.3

The city of Portsmouth, Va., uses a swamp water, and Norfolk, Va., has used a brown water for twenty years with entire satisfaction.

Many of the surface-waters of Massachusetts are colored brown, especially that of the Acushnet River, supplying the town of New Bedford. Experiments made with this water showed that its dissolved nitrogenous matter remained permanent for months without the development of "free ammonia," or other indications of decay.*

Writing to the author regarding sundry peaty waters which had come within his experience, Dr. Chas. Smart, of the army, says:

"No bad effect was attributed to any of these waters. I had one, however, which, with the characters just mentioned, showed many infusoria, rotifers, and amœboid

* Mass. Bd. Health, 1890, 547.

masses such as are seen in marsh-waters; but for these last characteristics I should have called it a peaty water. As it was a well-water, I suspected vegetable *débris* in the well, and directed investigation, when quite a depth of compacted dead leaves was taken out. This water was considered to have caused diarrhœa, and its use had been abandoned for some time before the sample was taken for investigation."

As illustrating, on the other hand, the undesirable character of some swamp-waters, the celebrated case of the Argo may be recited: In 1834 the ship Argo, in company with two other vessels, transported 800 soldiers from Algiers to Marseilles. All started in good health, and all three ships reached Marseilles on the same day. Of the 120 soldiers on the Argo all but 9 were attacked by fever, and 13 died. None of the 680 men on the other two vessels were taken ill, nor was there any fever among the crew of the Argo. On inquiry it was ascertained that all of those on the other vessels, and also the crew of the Argo, were furnished with water from a pure source, but that the supply for the soldiers on the Argo was derived from a marsh.*

A more modern illustration is afforded by the experience of Long Branch, N. J., in August, 1887. The town took its water-supply from Cranberry Creek, which rises in a cypress swamp about four miles to the west. It happened that at the time mentioned the dam on this creek gave way and the water, which is very heavily charged with peaty matter, was pumped directly into the mains without having the customary interval for sedimentation, clarification, and bleaching. The result was an epidemic of diarrhœa, which affected numbers of the summer visitors, and filled the New York papers with long articles of complaint.

An examination of the water, made at the time by Prof.

* Parke's "Hygiene."

A. R. Leeds, showed that out of 187 parts per million of total solids 92 parts were organic, and nearly the whole of this was oxidizable by potassium permanganate. Filtration remedied the evil, and no such trouble has since obtained.

It has been the author's fortune to meet with but few cases of illness traceable to peaty waters, and in all such instances the patients suffered from a mild and transient form of diarrhœa, caused by water from a low-lying, shallow lake or pond, surrounded by low wooded banks. Whatever be the morbific principle of such waters, it appears to be removed by suitable filtration.

Tidy is inclined to look with doubt upon the dictum that peaty water induces diarrhœa, for he finds the death-rate from such cause lower than the average in certain towns whose water-supplies are exceedingly peaty in character, although he admits that in some Irish towns furnished with peaty water the death-rate from diarrhœa is excessive.*

Mrs. E. H. Richards very properly points out that such peaty waters as are found unwholesome may owe their toxic qualities to the presence of materials other than the brown coloring-matter.

When we dwell upon the fact that the milder enteric disorders rarely get into the "death-rate," and that visiting strangers may suffer from a cause to which the acclimated natives are not susceptible. we appreciate that such data as Tidy furnishes do but emphasize what we believe to be a fact,' that in dealing with peaty water we must consider it as largely an unknown quantity, possibly entirely harmless, but also the possible centre of much trouble, especially if the amount of organic matter present be large. Even the same water may not at all times be equally potable, for, as J. W. Mallet has well said: "It seems quite conceivable that a water containing organic matter of any

* J. Chem. Soc. xxxvii. 319.

kind may be harmless at one time and harmful at another, when perhaps a different stage of fermentation or putrefactive change may have been entered upon, and special organisms may have made their appearance or entered upon a new phase of existence. Thus there might possibly be safety in drinking a peaty water, or water filtered through beds of dead forest leaves, when fresh; danger when, after a certain amount of atmospheric exposure, bacterial organisms had become developed; and safety, again, perhaps, after the growth of such organisms had fallen off, and more or less of the available organic matter had been consumed." *

When, therefore, the question arises as to the advisability of introducing a peaty water as a town supply, the possible unsatisfactory character of the same must always be borne in mind, and the municipal authorities should be prepared for the probable necessity of constructing a filtering-plant. Moreover, a distinction should be always drawn between a flowing water carrying fresh peaty material in solution and a water derived from a stagnant swamp. "In certain cases it may be a fact that the algæ decay rapidly, but that new growth absorbs the products of decomposition, so that they do not accumulate in the water. Shallow, stagnant bodies of water, which in the heat of summer are full of vegetable and animal life, become in time foul, because decay gets ahead ot growth and the products of decomposition accumulate."

Dr. Bartley has lately written upon the relation of water to paludal poisoning,† and has dwelt upon the observation that persons who drink the water of stagnant ponds in malarial regions suffer more than those who avoid the use of

* Schröder has recently observed that peat, particularly if it be of acid reaction, possesses the power of quickly destroying the cholera germ. He found the spirillum killed after an exposure of five hours to peat-dust.—J. Soc. Chem. Ind. xiii. 538.

† *Brooklyn Med. J.*, Jan. 1893.

such waters. He refers to the instance furnished by Laveran, a case where one detachment of soldiers partook of a certain well before dinner, while another detachment drank of the same water after a hearty meal. A large number of the first group of men became malarial, while of the second none contracted the fever. He explains this incident by the fact that the gastric juice of an empty stomach is neutral or alkaline in reaction, while in the second the gastric juice was acid and destroyed the organisms.

In the *Sanitarian* for August, 1892, Dr. Waggener writes: "In January, 1886, a company of forty healthy marines were sent to the navy yard at Pensacola, Fla. During their first year frequent attacks of malaria began to show themselves among these men, which increased in number during the second year, and during the third year the disease became so prevalent that, before August, twenty-five of the party were in the hospital at one time. During this year they were so broken down that they were all sent to Norfolk, Va., where they all recovered. These marines drank the water from a driven well at the yard. The officers and their families drank only from a cistern, and no case of malaria appeared among them, proving that the wells were probably the cause of the sickness among the marines.

"In 1875 the naval hospital at Pensacola was rebuilt. It proved to be a very unhealthy place, malarial diseases being very commonly contracted by patients and all others who came there. This continued until 1890. At this time there was a change in the water-supply. A cistern was constructed and the use of well-water from the driven wells was abandoned, with the cessation of malarial attacks. The soil at the location of the hospital is composed of a sandy top with a swampy marl underneath. This peaty soil contains organic matter, and in some way produced these diseases."

Laveran reaches the following conclusions upon this subject: "1st. There have been observed cases in which, in the same locality, persons living in identical conditions, but using drinking-waters from different sources, the one group being attacked in a large proportion, while the other group of persons are scarcely affected at all.

"2d. In certain otherwise unhealthy localities the paludal fevers have been seen to disappear by supplying pure drinking-water instead of the previously used stagnant waters.

"3d. In localities otherwise healthy one can contract intermittent fever by drinking water from an unhealthy locality.

"4th. Travellers in malarial countries have found that on boiling their drinking-water they escape the disease in a large proportion of cases."

Dr. H. Martyn Clark, of the city of Amritsar, India, in a paper read before the Scottish Geographical Society in April, 1892, says: "The malarial poison is usually breathed into the system, but it is, in my opinion, quite as commonly imbibed. Water is contaminated in two ways: either by the power it has of absorbing malaria which passes over its surface, or, in the case of wells, through the subsoil-water. * * * In 1884 a party of workmen, sent to repair a bridge over the Chuka, drank of this stream, and, out of thirty, only three escaped fever, while several of them died."

Dr. W. H. Daly, of Pittsburgh, Pa., writes:* "Observations and studies on the subject, and investigations made in various districts from Manitoba to Louisiana, and all along the southern coast of the Atlantic Ocean, and of Cuba, Yucatan, and certain districts in Mexico, lead the writer to the conclusions that so-called malarial disease is not easily, if at all, contracted by inhaling so-called malaria or bad air of the low, swampy, or new lands, but it is distinctly, if not almost exclusively, due to drinking water that has come

* *Medical Record*, Sept. 15, 1894.

into contact with and become infected with the malaria germs that exist in the earth and waters of the swamp and low lands. This germ does not ordinarily, if at all, float in the air during the day, nor does it find easily a vehicle in the fog or vapors of the night." *

Writing upon paludism, Dr. Chas. Smart says: "The propagation of malarial disease by means of drinking-water has of late years been accepted by those who have made a special study of the subject. Proof was difficult, because of the general and unquestioned acceptance of the doctrine of an aerial miasm as the cause of all malarial disease. When the requisite spot of malarial soil was not present to account by its exhalations for some obscure or anomalous case, its existence was assumed. But these obscure cases, when attention was directed to them, were found to be very numerous. They were common all over our Western Territories, on elevated grounds, where there was apparently no source of malarial exhalation, and these cases were always of a serious character; remittent fevers rather than simple agues. They were common in certain districts of the country in the winter season, when, in accordance with the theory of a malarial miasm exhaled into the atmosphere and inhaled into the lungs, the frosts of the season should have imprisoned all such exhalations, and these cases also were severe rather than mild. But in all these instances of serious malarial diseases without malarial soils to account for them the drinking-water used was derived from a malarious locality, and in some the prevalence and aggravated character of the sickness was proportioned to the amount of the organic impurity in this water. On the assumption that the water was impregnated with malaria from the soil, these

* A very full investigation, tending to show close relationship between paludal poisoning and water-supply, will be found in the Fifth Biennial Report of the North Carolina State Board of Health, 1893–1894.

obscure cases ceased to be obscure. But this is not an assumption, for there is a groundwork of fact to support it as solid as that which sustains the theory of the aerial transmission of the disease. The prevalence of these fevers has been decreased with an improvement in the water-supply. The remittents of our Western Territories have declined in frequency since the country became settled and a better water-supply was found than that of the ponds, ditches, and tanks used by the overland travellers. Recent reports from some of the most unhealthy districts of India show an extraordinary change in the insalubrity of the country coincident with the procurement of a supply of drinking-water from deep and carefully protected wells."

In the report of the Michigan State Board of Health, 1882, the proposition is made by Dr. Mulhern that the presence of decomposing sawdust in water is a cause of malaria. Whether or not this can be proven, it is unquestionably true that such material can render water highly objectionable. In certain portions of Michigan the enormous lumber trade has forced upon the people sanitary problems of very unusual character.

"In some places large areas of low ground, but little above the water-level of the adjacent lake or river, have been built up with sawdust until sufficient elevation has been secured to build houses on these made-lands. To such an extent have whole blocks and streets been built up with this sawmill waste that the epithet 'sawdust city' applies with singular force to some of the most enterprising business centres.

"Take as an example the water from an open well in Grand Haven, excavated in a sawdust area, the well 7 or 8 feet deep, and the water-level only 3 feet below the surface. The water contained 260 parts solids in 1,000,000 parts of water, 170 parts being volatile and organic. It contained

1.5 parts free ammonia, and 1 part albuminoid ammonia. It contained so much combustible matter and nitrates in solution that on evaporating a litre in a large platinum basin and heating the residue at one edge a brisk deflagration spread over the whole dish.

"1. These sawdust waters all contain an amount of organic matter sufficient to condemn them for potable and culinary use.

"2. They all contain resinous extractive matter in solution.

"3. They all contain nitrogenous material capable of yielding albuminoid ammonia greatly in excess of the sanitary limit.

"4. They contain all the chemical elements necessary to sustain low forms of plant-life.

"5. In the presence of so large an amount of organic matter and the chemicals of plant-life, these waters may become dangerous by nourishing and reproducing the germs of epidemic disease, should they find lodgment therein."

However interesting to the microscopist may be the lower forms of animal and vegetable life, with which many of our surface-waters are often crowded, it is yet an open question whether or not they are of any importance to the sanitarian. Odors, variously described as "musty," "fishy," "cucumber," "green-corn," "horse-pond," and the like, are frequently produced by the death and decay of these little organisms, especially of those known as algæ; but, however objectionable these odors and tastes may be from an æsthetic standpoint, it has not been proven that they are productive of disease. When the small plants are themselves swallowed, "they act mechanically chiefly, perhaps like unripe fruit, when affecting the health at all, in causing diarrhœa; but the filtered water is harmless." *

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* First Report Mass. Bd. Health, 1879.

The possibility of preventing the growth of these minute organisms will be considered in a subsequent chapter.*

Although natural waters are to be found bearing in solution most varied assortments of mineral ingredients, yet such cannot be considered potable, except in the sense that they are medicinal, and they consequently do not find place in the present writing. When those minerals are present, however, which give to the water the characteristic known as "hardness," the case is quite different, for such a property obtains, to a greater or less degree, in every public supply. As to the wholesomeness of such a water, there is widespread opinion that a high degree of hardness is not compatible with safety; but although hard waters do often produce certain intestinal derangements in persons not accustomed to their use, there are no sufficient statistics on record tending to confirm the popular belief that they lead to the formation of urinary calculi. It is a matter of common observation that sudden change from the use of a pure, soft water to one equally pure, but harder, or *vice versa*, results in temporary intestinal derangement, showing the difficulty to be due rather to the change than to the inherent character of the water employed. As has been pointed out by Prof. Drown, the waters of the south of England are exceedingly hard, but the statistics do not show an increase of death-rate resulting therefrom. While considering the wholesomeness of hard water, the English Rivers Pollution Commission (Sixth Report) collected the following statistics, the comparison having been made between towns of the

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* A. R. Leeds refers to the oily nature of some of the products of plant growth. The acid residue of such oily compounds being volatile and of bad taste and smell, carbonic acid will, at times, liberate the objectionable acid, thus producing a taste or smell where none existed previously. He has known cases of such liberation during the manufacture of "soda-water." (Am. Water Works Asso., xii. 193.)

same class, in which the general conditions of life are similar. The conclusion was: "Where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water."

TOWNS SUPPLIED WITH SOFT WATER.

Kind of Town.	Number of Towns.	Average Population.	Average Annual Mortality per 1000 Inhabitants.
Seaport	5	162,801	29.4
Inland manufacturing	5	172,860	29.7
Inland non-manufacturing	8	10,751	25.4
Watering-places	5	48,430	19.5

TOWNS SUPPLIED WITH MODERATELY HARD WATER.

Seaport	3	226,172	32.1
Inland manufacturing	8	108,715	26.9
Inland non-manufacturing	4	62,372	26.0
Watering-places	3	33,480	19.2

TOWNS SUPPLIED WITH HARD WATER.

Seaport	6	116,406	25.1
Inland manufacturing	5	144,981	25.5
Inland non-manufacturing	20	29,169	23.2
Watering-places	12	53,170	20.4

In an article on "The Importance of Magnesia in Drinking-water" * Percy Frankland shows that a very great percentage of the population of England are to-day using waters containing from 40 to 60 parts of MgO per million; and that, consequently, the prejudice existing against magnesian waters, on account of their supposed production of calculi, goitre, and cretinism should not be given undue importance

* International Congress of Hygiene, London, 1891.

until a thorough investigation has demonstrated that it is founded upon truth.

Lying between ordinary hard waters and those of a true mineral character is a group of waters, principally of artesian origin, which contain sundry objectionable mineral ingredients, such as magnesium chloride, hydrogen sulphide, and the like, and which would hardly be considered potable did they occur in well-watered regions, but which are thankfully received by people very willing to take almost any water they can obtain.

Turbidity is exceedingly common in the river-waters of this country, particularly in those of the great central basin. The quantity of suspended claylike material present naturally varies in each stream with the conditions of the season, being at times entirely absent in some of them, while with others the existence of more or less muddiness appears to be a constant characteristic.*

With reference to the influence of the suspended mineral matter upon health, we find some conflict of opinion. It is an unquestioned fact that very roily water is ingested by many of our communities with no traceable evil results, but the preponderance of testimony goes to show that immunity is attained by continued use, and that the visiting stranger is not upon the same platform of safety with the acclimated native. To quote a typical instance: "In 1868 the right wing of the 92d Highlanders, going up the River Indus, suffered from diarrhœa from the use of the river-water, which at the time was very muddy. The left wing of the same regiment

* Ockerson reports that four different surface-samples of Mississippi river water contained 576, 788, 1030, and 348 parts per million of sediment. On July 2, 1894, the same river-water, at New Orleans, contained 2360 parts per million of solids, mostly silt. Below the junction of the clear Mississippi with the muddy Missouri, the two waters flow on for many miles, side by side, with a distinct line of division.

used water from the same source, but precipitated the suspended matters with alum, and had no diarrhœa. The right wing then adopted the same plan with like success." *

In reply to the claim so often advanced that turbidity is a positive advantage, as tending to remove objectionable material from a sewage-polluted river-water, it should be stated that suitable arrangements for sedimentation must be furnished, otherwise no advantage can be expected from the mere presence of the suspended mineral ingredients. It is a well-known fact that precipitating solids will drag down with them other finely divided substances which, if left to themselves, would require long periods of time for complete sedimentation, and that even soluble salts will often be in part carried down by the same cause, as every student of quantitative analysis knows to his sorrow.

It may readily be conceived that, acting in obedience to this principle, the depositing silt would gather to itself, and carry with it, many germs of disease which, if left to themselves in clear water, would require much longer time to fall; but that there is any advantage to be looked for in using a turbid water without sedimentation, and thereby swallowing turbidity, germs, and all, is scarcely rational.

The following is in illustration of the influence of turbidity in causing a more rapid deposition of bacteria diffused throughout a body of water. The results represent the relative numbers, per cubic centimetre, at the surface of a body of water, and at varying depths in the same, under the condition of clearness and also of material turbidity.

The experiment was conducted with a tall tin vessel, one foot in diameter, and tubulated at intervals of one foot, for drawing samples. The time of settlement was made two hours; and the numbers of bacteria found per cubic centi-

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* Parke's "Hygiene," I. 341.

metre at the successive depths are stated in terms of the number in the surface sample, that being called one hundred.

	Muddy Water.	Clearer Water.
Surface	100	100
Depth of one foot	134	125
" " two feet	166	142
" " three feet	186	169
" " four feet	266	254

Two hours of settlement were not enough to bring out marked contrast between the waters, although the principle was sustained.

"As the result of one year's observation made by Theobald Smith a relation was found between turbidity and the presence of bacteria. Bacteria were most abundant in winter, January and February having the highest average; August, September, and October, the months of the greatest prevalence of typhoid fever, having the lowest. Bacteria, most of which were harmless, were most abundant after heavy rains, and their presence in association with turbidity proved the then source to be from the washing of the surface of the soil.

"In the latest bacteriological report on Potomac water Theobald Smith adheres to this statement, and says that fecal bacteria and turbidity were coincident; that is, that rainfall carries into the Potomac whatever may happen to be on the surface of the soil—clay, manure from the fields, inorganic or organic matter of any sort."

The really serious item of contamination, the one to which the sanitarian's attention is most quickly drawn, is that of sewage introduction, and a consideration of the questions arising upon this topic dwarfs all others into comparative

insignificance. Shall a water once polluted with sewage-material be again used for human consumption? If there be danger in such use, what is its nature, what is its extent, and are there available means for averting it? These are popular questions of the day with which the sanitarian has to grapple.

It would hardly be wise to take the reader's time with a *résumé* of matters, possessing only historic interest, pertaining to this topic; suffice it to say that, within the very recent past, strong views were entertained concerning the self-purification of streams, and also upon certain features of natural and artificial filtration, which we now believe to have been erroneous. That polluted public water-supplies have caused widespread illness and death is established beyond a peradventure, and, from among the many illustrations that might be cited, the author offers the following in evidence, some of the data having been collected by himself or within his personal experience:

In the autumn of 1887 the city of Messina, Sicily, was visited by an epidemic of cholera. The plague lasted from September 10th to October 25th, during which time there were some 5,000 cases and 2,200 deaths. Although for a time the number of daily cases was excessive, running as high as 400, the ordinary number was about 70. The population was stampeded, falling from 71,000 to about 25,000. The government felt that a very possible cause for the rapid spread of the scourge lay in a contaminated drinking-water, and an inquiry, resulting in a development of the following facts, fully confirmed the suspicion: The water as it left the gathering grounds in the mountains was of excellent quality, but it was conveyed to the city in a conduit entirely open. Those who are familiar with European customs will remember that the washing of soiled clothing is there largely an out-of-door occupation, conducted in the

nearest available water-course. For the benefit of the Messina washerwomen a portion of the public water was deflected, before reaching the walls, and turned into neighboring washing-pools of stone. A fair proportion of this deflected water, after having been used for laundry purposes, found its way back into the channel, and continued its course to the city. Further contamination occurred within the town itself, for the reason that the mains of the distributing system were of unglazed tile, badly joined, and were laid in the immediate vicinity of unglazed tile sewers, also very leaky. The sewers were at times found on top of, and parallel with, the water-mains.

Acting upon its conviction as to the cause of the great mortality, the government sent tank ships to the mainland, filled them with pure "Serino" water, supplied the people therewith, and the daily number of cholera cases immediately fell from seventy to five; or, to quote an expression of the time, "the plague ceased as if by magic." An entirely new and efficient distributive system has since been introduced, the open conduit has been replaced by modern pipe and the city has escaped further visitation by cholera.*

Prof. W. T. Sedgwick gives the following description of the outbreak of cholera at Genoa, Italy, in 1884:

"Cholera had appeared in Spezia, some fifty miles away; but after cholera had been raging in Southern Europe nearly two months, Consul Fletcher of Genoa wrote to the authorities in Washington: 'I do not believe the officials in any city in Europe could be more watchful or take more extreme precautions to ward off the epidemic than those in authority in Genoa. The result is that Genoa is in as healthy a state

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* The influence of the washerwomen in spreading cholera in Messina reminds us that the great epidemic at Cuneo, Italy, in 1884, resulting in 3344 cases, was traced to identically the same source. Infected linen had been washed in a brook communicating with the public water-supply.

to-day as it is possible for human agency to make it, considering its peculiar construction and its proximity to the sea.' The cholera was then but fifty miles distant; but for a month later the city retained its healthfulness, when suddenly the cholera appeared, and in one week one hundred and sixty-nine people died with this disease, nine-tenths of whom were supplied by one of the three public water-supplies of the city.

"Upon investigation it was found that upon the stream which was the source of this water-supply, thirteen miles from the city, between one thousand five hundred and two thousand laborers were at work upon a railroad, and in the previous week cholera had broken out among them. They washed their clothes in this stream, and some of their bowel discharges probably also found their way into it. On the tenth day after the cholera appeared in Genoa, this source of water-supply was cut off, and the portion of the city which it served was supplied from one of the other sources. The daily deaths from cholera immediately decreased, and in six days the number had fallen from thirty-eight to ten. The whole number of cases in the sections of the city supplied by the polluted water was four hundred and forty-four, and in the two sections supplied by public water-supplies of unpolluted water the whole number was fifty-five." *

An interesting case, showing the relation of water-supply to disease, was presented to the author recently. The village of Jessenitz, some 40 miles from Hamburg, was, until lately, of an unsavory sanitary reputation, typhoid fever and

* "In the town of Askhabad, on August 3, 1892, there were only eleven patients in the hospitals, and they were convalescent. The epidemic was over and the people were congratulating themselves on their escape. On that night twelve soldiers were taken sick with the disease. On the following day 400 persons fell ill, and within a few days there were over 400 deaths in the town. It was afterwards learned that some soldiers, just recovering from cholera, had gone to the stream which furnished the water-supply, and had washed their clothes. The epidemic followed as a very natural result."—Ohio Board of Health, 1893.

diphtheria having been plentiful and frequent. About 30 feet below the village site is a stratum of clay, above which lies the water-bearing layer into which common open wells of the inhabitants were sunk. Suspicion having been cast upon the water-supply, new wells were driven near the old sites to a depth of seventy feet, passing through the deposit of clay. The old wells were closed and the good sanitary results were both immediate and marked. None of the former trouble has been experienced.

In 1890 two violent outbreaks of typhoid fever occurred in the valley of the Tees River.*

The Tees is a small stream of northern England, about seventy miles long, and navigable for about four miles from its mouth.

Most of the towns of the valley take their water-supplies from the river, but a large scattered population receives water from other sources. The estimated population using Tees water at the time of the outbreak was 219,435, and the number not using such water was 284,181.

In many places, especially in the towns, the river receives all sorts of polluting additions, which are carried on by the current to the intakes below. During dry weather, the stream recedes considerably, leaving uncovered its rocky foreshores, which accumulate filth of every variety, and retain the same until, by reason of heavy rain, the river suddenly rises and sweeps the refuse downward towards the towns nearer the sea.

The result produced upon the thoughtless public, of such an extra and concentrated dose of sewage material added to their water-supply, is best shown graphically by the accompanying chart, where it will be observed that increase of rainfall is followed by increase in cases of typhoid fever

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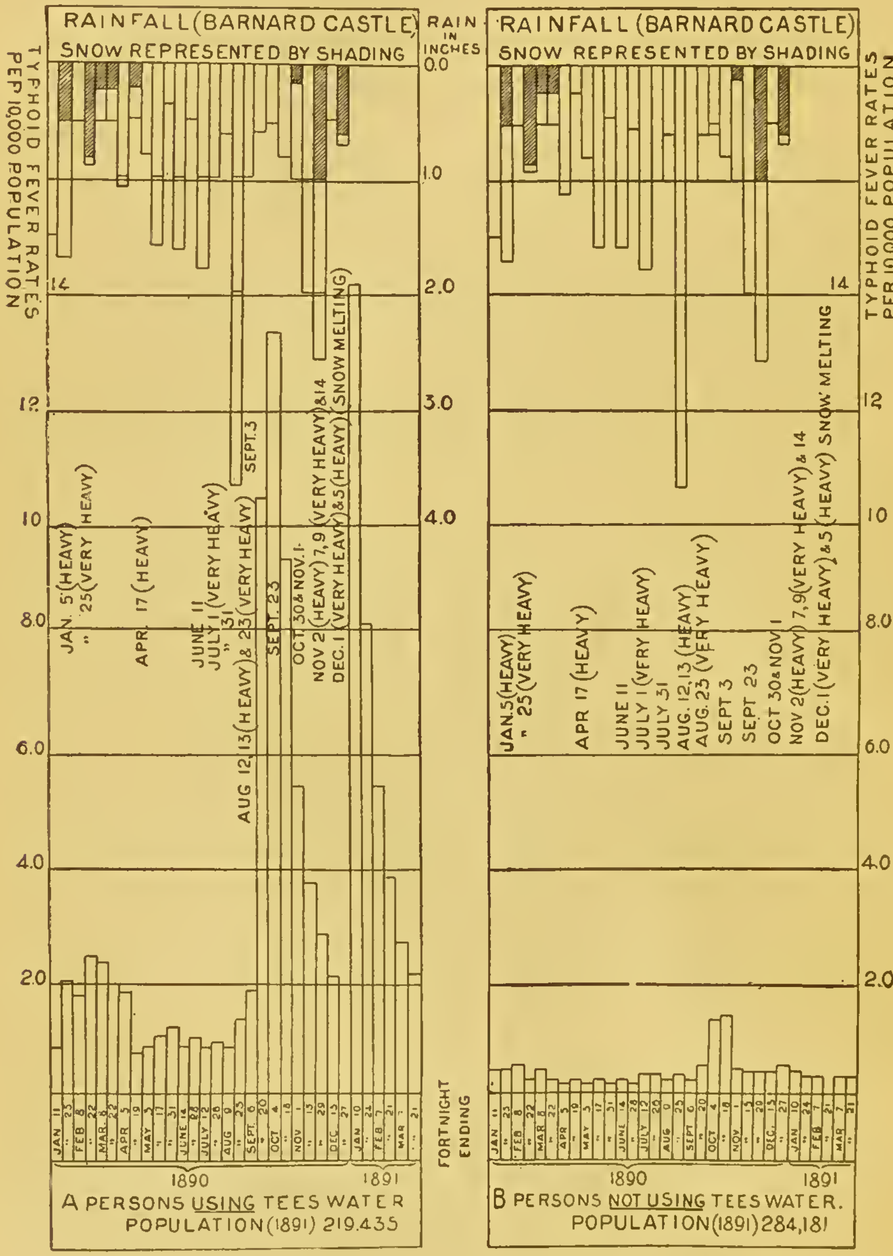
* See 21st Report of the London Local Government Board.

among the 219,435 persons using the Tees water, after an interval corresponding to the incubation period of the dis-



RAINFALL AND TYPHOID FEVER IN THE TEES VALLEY, ENGLAND.

ease, while no appreciable result is noticed among 284,181 people of the same district, using other sources of supply.

The " typhoid rates " given in the chart are " cases," not "deaths."

It is especially worthy of note that " increased rainfall " is separated from " increased typhoid " by an interval corresponding with the incubation period of the disease.

It fell to the author's duty to investigate certain points relating to the typhoid epidemic occurring in the valley of the upper Hudson during the autumn and winter of 1890-91, and the facts seem especially instructive.

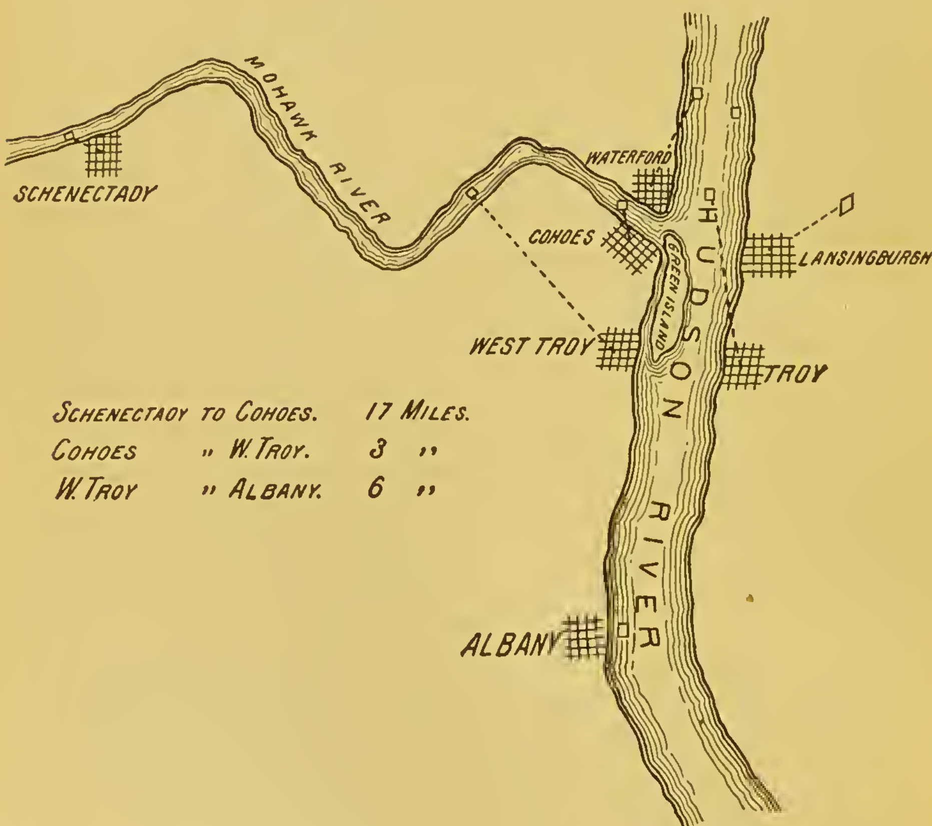
By a glance at the accompanying chart, the locations will be observed of the several cities and towns situated at and near the junction of the Mohawk and Hudson rivers. Every one of these centres of population drains into the river on whose banks it is situated, and each of them, except Lansingburgh, takes all or the greater portion of its water-supply directly from such river by means of pumps. Mark this difference, however, Waterford and Troy are supplied with Hudson River water above the junction with the Mohawk; Lansingburgh is furnished with water from the hills east of the town, and the village of Green Island obtains its water from wells driven into its sandy soil. The others use Mohawk or Mohawk-Hudson water.

The several intakes are indicated on the chart by squares. Under date of April 11, 1891, the Health Officer of Schenectady wrote the author: " The marked increase in typhoid fever began in July, 1890, and has just let up. We have had about 300 cases. Doctors have not been particular in reporting them, and we have had so many cases of anomalous fevers that diagnosis is questionable. Seventy deaths have been reported." Permit me to say that it was not the rule during this epidemic for physicians to do their whole duty in reporting cases. I knew of one instance in which only two or three cases were reported out of twenty-five. Schenectady is a very old town (of 20,000 inhabi-

tants), and its sewerage system is doubtless none of the best, but its drainage eventually reaches the Mohawk and is carried onward with the current.

The following information was obtained from Dr. Leo, Health Officer of Cohoes, and from Dr. Peltier, his predecessor. Population of Cohoes is 22,000.

The epidemic of typhoid began in Cohoes about the end of October, 1890, and ceased about the middle of the following March. Altogether there were about 1,000 cases. The cases were mild in character, resulting in very few deaths. Cohoes takes its entire water-supply from the Mo-



hawk and returns its sewage into the same river. Boiling of water for drinking purposes was recommended, and no typhoid developed among families who followed the recom-

mendation, except in those instances where members of such families drank unboiled water while at work away from home. A portion of the city is owned by the great Harmony Knitting Mills, and is built up with tenements for their employees, of which there are many hundreds. These tenements are kept in excellent repair and the plumbing is the best in the city, but extends to kitchen sinks and drains only. No water-closets are employed, as each house is furnished with privy vault in backyard. Typhoid was especially bad in this quarter. The Cohoes Health Officer has professional occasion to visit in Waterford (population 5,400) and in Lansingburgh (population 10,000), which towns are connected with Cohoes by bridges. He reports that hardly a case existed in either of those towns, and it is to be noted that one of them draws water from the upper Hudson above the Mohawk junction, and the other is supplied from the hills.

West Troy is situated on the Hudson and sewers therein, but by aid of the chart it will be noticed that its water-supply comes from the Mohawk some distance above Cohoes. Its population is 13,000. The following information was obtained from Dr. McNaughton, Health Officer:

"Epidemic typhoid began the last of November. At meeting of Health Board, about December 15th, fifty cases were reported. Of these, forty-two had used Mohawk water, the remainder well-water. On December 20th, the Mohawk supply was shut off and arrangements made with the town of Green Island (which village, by the way, had no fever) to use a portion of its supply. One week thereafter the weekly report of cases showed fifteen, and the second week thereafter but one case was reported. The Green Island supply was used one month. Upon returning to the Mohawk supply in the middle of January, a slight increase in typhoid was observed. Total number of cases exceeded 100. The

fever, as in other places, was very mild, resulting in ten deaths."

Troy is situtated directly opposite West Troy. Its population is 65,000. Its water-supply comes partly from lakes back in the hills, partly from the Hudson above the Mohawk junction.

There were very few cases of typhoid in Troy during the year, and of those few a large percentage were imported from Schenectady and West Troy.

Troy dumps 8,000,000 gallons of sewage into the Hudson daily.

Six miles below Troy is the city of Albany; population, 100,000. Albany takes its water through an intake in the side of the wharf, directly in front of the city. Not only does sewage from the upper Hudson and Mohawk flow toward it, but during flood tide and south wind, the return of its own sewage from the sewer outfalls below has been proven by the floating of buoys.

The typhoid epidemic began in Albany the last of December, 1890. The disease was very mild in character, resulting in sixty-two deaths during the months of January, February and March, 1891. The total number of typhoid cases reported during the same period was 411, but this figure I have reason to know is absolutely unreliable. Albany experienced a very serious epidemic during the winter of 1890–91, and the alarm was widespread, of that there can be no question. A small portion of the city receives its water-supply from an inland gravity source. Typhoid was not nearly so plenty in that section, only eighteen cases having been reported to the end of March.

At Van Wie's Point, four miles below Albany, the laborers employed in cutting ice for the great ice-houses had typhoid fever break out among them during January. They used river water for drinking purposes.

Typhoid germs were carefully looked for in the water and were not found. But such a negative result does not appear surprising. There are those who hold that this outbreak of typhoid fever is to be explained in some other way than by attributing it to a contaminated water-supply, but when we bear in mind that, out of this group of closely situated cities and towns, all of those which used the Mohawk-Hudson water contracted the fever, and that all those which did not use such water escaped, there is much food for thought.

Two important cases of typhoid outbreak must be added to those given, because, though often quoted, and doubtless familiar to most readers, the lessons they teach are too valuable to risk losing from the memory. The first is from a description by Dr. E. F. Smith:

"The city of Plymouth, Pa., contains a population of about 8,000. In this small community within a period of a few weeks there were more than 1,000 cases and 100 deaths from typhoid fever. The epidemic was studied on the spot by competent New York and Pennsylvania physicians, so that no doubt is left either as to the nature of the disease or as to the method of its introduction and spread.* The facts, sifted and tested by rigid and expert scientific methods, are as follows: The general water-supply of Plymouth is obtained from a mountain brook, a number of dams being thrown across the stream for this purpose. During part of the winter of 1884-5, owing to the deep freezing of this stream, the hydrant water was taken from the neighboring river, Susquehanna. There are very few houses on the banks of the mountain brook, and it would seem that the stream is unusually well protected from sources of contamination. During the time that the stream was frozen a

* "Report upon the Epidemic of Typhoid Fever at Plymouth, Pa." By Lewis H. Taylor, M.D., of Wilkesbarre, Pa.

man came from Philadelphia sick of typhoid fever. He had contracted the disease at a place from which three other persons, sick with fever, had been removed to the hospital. This man was cared for in a house near the source of this mountain stream, or at least considerably above where the city water-supply was procured. The discharges from the bowels of the sick man were not disinfected. They were thrown by the nurse on the deep snow of a sidehill sloping toward the stream which was not over forty feet distant. A sudden rise in the temperature toward the close of March caused a general thaw, and the melted snow of the hillside with its mass of typhoid poison was swept into the stream. At just this time, owing to the rise of the water in the brook, the Susquehanna river water was shut off from the water mains, and that of the brook turned on again. In this way the typhoid poison was pumped to all parts of the city. In about two or three weeks hundreds of cases of fever developed, and these were confined exclusively to persons who used the hydrant water. No cases were traceable to well-water except much later, and by secondary infection. Whole groups of families using well-water or river-water exclusively escaped entirely. In parts of the city where the use of well-water was the rule and the use of hydrant water the exception, only those families suffered which used the latter. One notable instance is mentioned by Dr. Taylor where in the upper end of the city one family only suffered from the disease. It was supposed at first that all in that vicinity used well-water, but further inquiry showed this one family to have been in the habit of catching and using the hydrant water which leaked from the main aqueduct on its way down into the city, preferring the pure water of the mountain stream to that of the foul wells of the neighborhood. Such cases are, of course, no argument in favor of a return to the use of well-water, but only one for greater

care to prevent accidental contamination. This outbreak speaks volumes in favor of the specific nature of the typhoid fever poison.

The cost of this outbreak, in actual cash, is fortunately well established, and is deserving of attention by those charged with the care of the public health. It is itemized as follows :

Loss of wages for those who recovered	$30,020.08
Care of the sick	67,100.17
Yearly earnings of those who died	18,419.52

The second instance, above referred to, is described by Professor Frankland, and is a classic in water literature:

"The outbreak of typhoid fever occurred at the village of Lausen, near Basel, Switzerland, and it was exhaustively investigated by Dr. A. Hagler of Basel, who has given a full account of it in the Deutsches Archiv. f. Klin. Med. xi. The source of the poison was traced to an isolated farm-house on the opposite side of a mountain ridge, where an imported case of typhoid, followed by two others, occurred shortly before the outbreak. A brook which ran past this house received the dejections of the patients, and their linen was washed in it. The brook was employed for the irrigation of some meadows near the farm-house, and the affluent water filtered through the intervening mountain to a spring used in all the houses of Lausen, except six, which were supplied with water from private wells. In these six houses no case of fever occurred, but scarcely one of the others escaped. No less than 130 people, or seventeen per cent. of the whole population, were attacked, besides fourteen children, who received the infection whilst at home for their holidays and afterwards sickened on their return to school.

"The passage of water from the irrigated meadows to

the spring at Lausen was proved by dissolving in it, at the meadows, 18 cwt. of common salt, and then observing the rapid increase of chlorine in the spring water; but the most important and interesting experiment consisted in mixing uniformly with the water 50 cwt. of flour, not a trace of which made its way to the spring, thus showing that the water was *filtered* through the intervening earth, and did not pass by an underground channel.

"These are the main features of the case, according to the works above cited. It affords a clear warning of the risk attending the use, for dietetic purposes, of water to which even so-called *purified* sewage gains access; notwithstanding that, as at Lausen, such water may have been used with impunity for years, until the moment when the sewage became infected with typhoid poison." *

When it is remembered that much of the Chicago sewage flows into Lake Michigan, and that until recently the intakes supplying the city with the lake-water were situated only a few hundred feet off shore, a comparison of the typhoid death-rates before and after the driving of the four-mile tunnel is suggestive. The tunnel was opened December 3d, 1892.

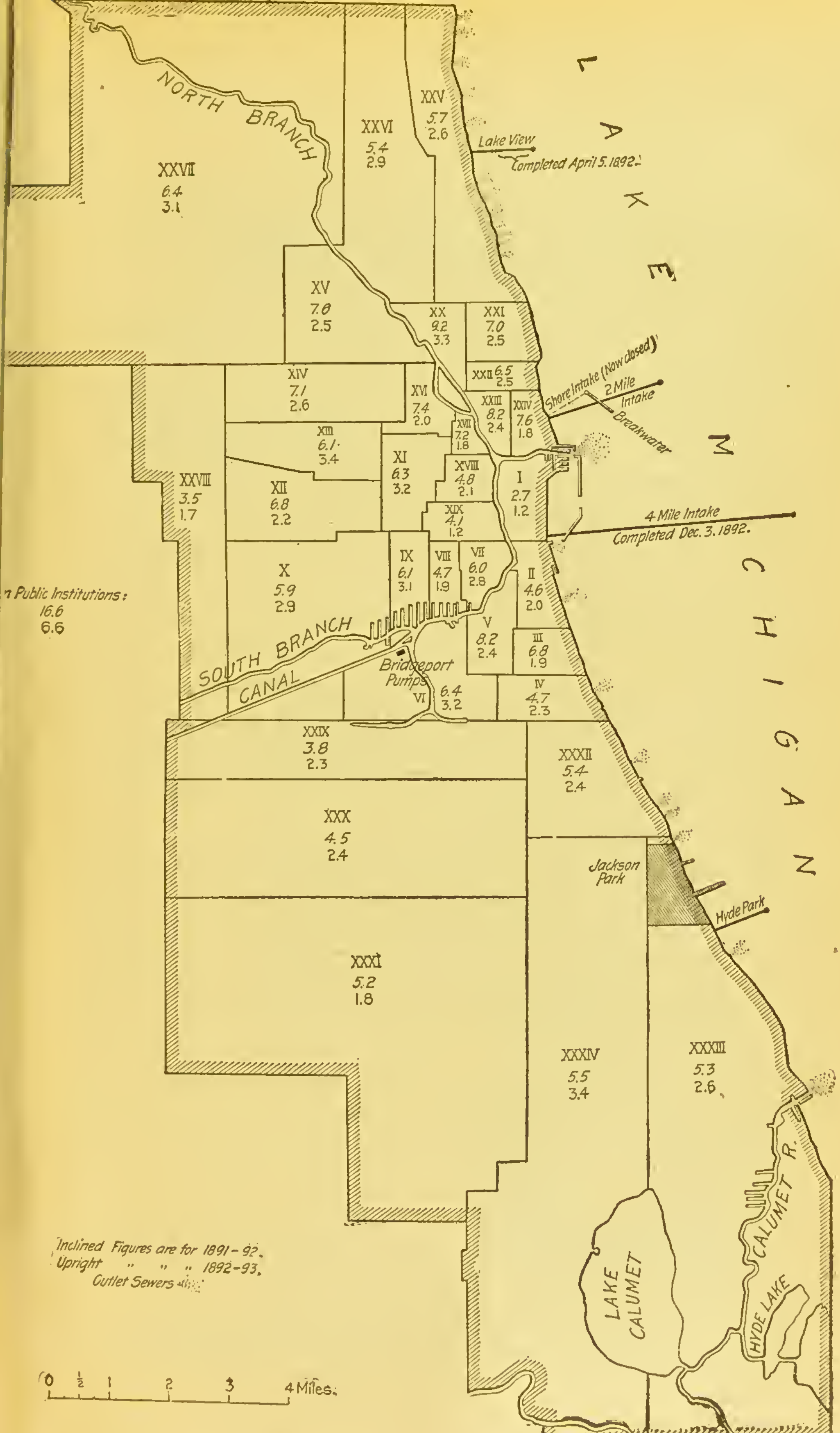
	Year ending Sept. 30, 1892.	Sept. 30, 1893.
Deaths in Chicago from typhoid fever...	1790	712
Per cent of typhoid deaths to total deaths	6.72	2.64

This is better seen, and in more detail, by consulting the following map, kindly furnished by the *Engineering News.*

Much as the new tunnel has done for Chicago, the difficulty has not as yet been entirely remedied, as is shown by the following abstract and ward map (page 39) published by the Chicago *Tribune* of Sept. 28, 1895:

"Typhoid fever is epidemic in Lake View. While the

* *Nature*, XIII, 447.



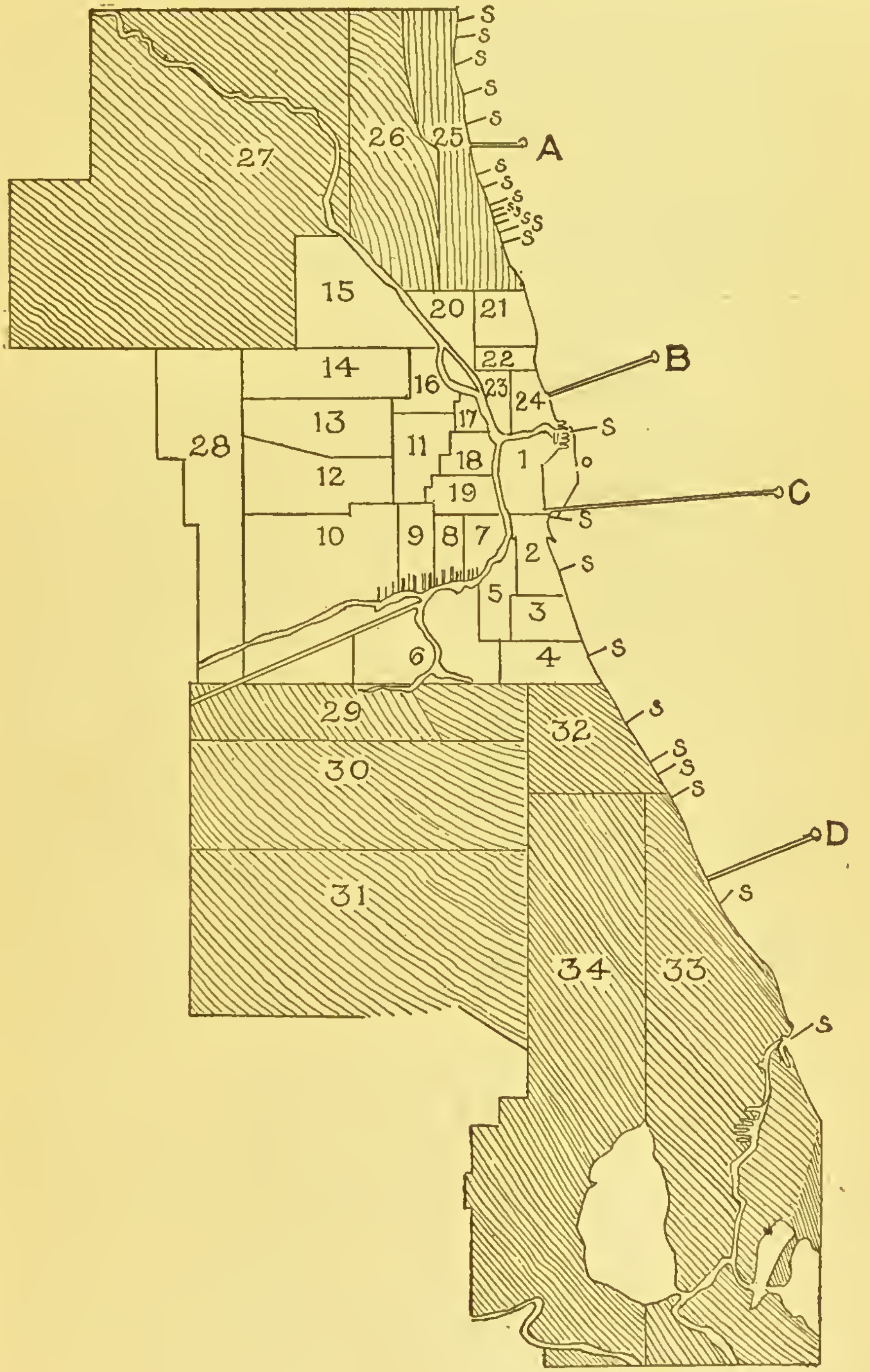
MAP OF CHICAGO SHOWING BY WARDS THE PERCENTAGES OF DEATHS FROM TYPHOID FEVER TO TOTAL MORTALITY AND THE WATER WORKS INTAKES AND SEWER OUTLETS FOR THE YEARS ENDING SEPT. 1892, AND SEPT. 30, 1893.

spread and prevalence of the disease are not so great in Hyde Park and the Town of Lake, still conditions in these two sections of the city are so severe as to cause alarm. In Lake View it is reported there are at least 1000 cases of typhoid fever now. There is scarcely a block in the district without one or more cases.

"The whole trouble rests with the impure water-supply, and so long as the residents drink it without boiling it they will put into their systems the pollutions that permeate the lake both north and south of the Lake View intake tunnel. North of the tunnel five sewers empty into the lake, and just south of it there are eight more. That this is the cause of the unusual number of cases of typhoid fever in the district is evident. The disease is only normal in the area south of Chicago avenue and Thirty-ninth street. All of the West Side is particularly free. This is because the district between Chicago avenue and Thirty-ninth street is supplied with water through tunnels from intake cribs two and four miles out in the lake.

"From Thirty-ninth street south to the city limits the disease is prevalent, but cannot be said to be epidemic. The same causes operate to create the disease there as in Lake View. Both Hyde Park and the Town of Lake are supplied with water from the Sixty-eighth street pumping station. At this station 35 per cent. of the water pumped is said to be pure, but the other 65 per cent. is polluted. Like Lake View the supply is taken from an intake crib only a mile from the shore line and in the midst of the sewage and refuse deposits of the South Side."

Attention is here asked to the following table (taken from *Engineering News*, April 21, 1892) giving typhoid statistics for the cities of Chicago, Philadelphia, and New York. The influence for good of the much purer New York water-supply is apparent, as also is the fact that typhoid is on



MAP SHOWING TYPHOID-FEVER DISTRICTS.

S—Sewers emptying into the lake; *A*—Lake View one mile crib; *B* and *C*—Two and four-mile cribs supplying district not infected; *D*—One and two-mile Hyde Park and Town of Lake crib. Shaded wards are where disease is epidemic.

the decrease at the metropolis, while the reverse is shown by the figures for the other two cities, where an increase of population is accompanied by an increased contamination of the sources of water-supply.

DEATH-RATES PER 10,000 INHABITANTS FROM ALL CAUSES, AND FROM TYPHOID IN CHICAGO, PHILADELPHIA, AND NEW YORK, FOR THE 22 YEARS 1870 TO 1891, INCLUSIVE.

Year.	Chicago.		Philadelphia.		New York.	
	All Causes.	Typhoid.	All Causes.	Typhoid.	All Causes.	Typhoid.
1870	246	9.00	227	6.06	288	4.47
1871	209	8.14	221	4.47	282	2.62
1872	277	14.26	262	5.09	337	3.98
1873	252	7.15	203	4.85	296	3.19
1874	205	5.34	197	5.95	279	2.96
1875	194	5.09	223	5.25	294	3.60
1876	204	4.00	217	9.22	274	3.02
1877	182	3.61	188	6.37	236	3.10
1878	165	3.24	179	4.61	237	2.81
1879	181	4.38	172	3.82	241	2.28
1880	208	3.40	209	5.88	264	3.08
1881	257	10.52	225	7.43	309	4.77
1882	236	8.24	226	7.33	295	4.02
1883	199	6.22	221	6.38	257	4.72
1884	198	5.62	215	7.13	257	3.49
1885	187	7.46	225	6.42	254	2.88
1886	195	6.86	206	6.36	258	2.99
1887	203	5.01	218	6.25	261	2.82
1888	190	4.52	200	7.72	261	2.37
1889	176	4.70	199	7.07	251	2.51
1890	182	3.40	207	6.36	246	2.16
1891	231	16.64	214	6.27	257	2.26
Averages	208	6.90	212	6.20	270	3.19

Hazen, in his recent work on "Filtration of Public Water-Supplies," gives the following data for cities of 50,000 inhabitants for the year 1890, compiled from the U. S. census.*

* Hazen also gives the following annual typhoid death-rates per 10,000 inhabitants, showing present improvement:

London,	1881–1890, average	1.8
Dresden,	1878–1888 "	1.7
Hamburg	" "	3.9
Berlin	" "	3.1

Two cities with less than 50,000 inhabitants with exceptionally high death-rates have been included, and at the foot of the list are given corresponding data for some large European cities of 1893.

TYPHOID FEVER DEATH-RATES AND WATER-SUPPLIES OF CITIES.

City.	Population.	Deaths from Typhoid Fever.		Water-supply.
		Total.	Per 10,000 living.	
Birmingham..	26,178	69	26.4	Five Mile Creek
1. Denver	106,713	232	21.7	North Platte River and wells
2. Allegheny....	105,287	192	18.2	Allegheny River
3. Camden......	58,313	77	13.2	Delaware River
4. Pittsburg.....	238,617	304	12.7	Allegheny and Monongahela rivers
Lawrence	44,654	54	12.1	Merrimac River
5. Newark......	181,830	181	10.0	Passaic River [gallons daily
6. Charleston...	54,955	54	9.8	Artesian wells yielding 1,600,000
7. Washington. .	230,392	200	8.7	Potomac River
8. Lowell.......	77,696	64	8.2	Merrimac River
9. Jersey City...	163,003	134	8.2	Passaic River
10. Louisville....	161,129	122	7.6	Ohio River
11. Philadelphia..	1,046,964	770	7.4	Delaware and Schuylkill rivers
12. Chicago.. ...	1,099,850	794	7.2	Lake Michigan
13. Atlanta......	65,533	47	7.2	South River
14. Albany......	94,923	67	7.1	Hudson River
15. Wilmington..	61,431	43	7.0	Brandywine Creek
16. St. Paul......	133,156	92	6.9	Lakes [reservoirs
17. Troy........	60,956	42	6.9	Hudson River and impounding
18. Los Angeles..	50,395	34	6.7	Los Angeles River and springs
19. Nashville	76,168	49	6.4	Cumberland River
20. Cleveland....	261,353	164	6.3	Lake Erie
21. Richmond....	81,388	50	6.1	James River [reservoir
22. Hartford.....	53,230	32	6.0	Connecticut River and impounding
23. Fall River....	74,398	44	5.9	Watupa Lake
24. Minneapolis..	164,738	94	5.7	Mississippi River
25. San Francisco	298,997	166	5.6	Lobus Creek, Lake Merced, and
26. Indianapolis..	105,436	57	5.4	White River [mountain streams
27. Cincinnati....	296,908	151	5.1	Ohio River
28. Memphis	64,495	33	5.1	Artesian wells
29. Reading.	58,661	29	4.9	Maiden Creek and springs
30. Baltimore....	434,439	202	4.7	Impounding reservoir
31. Omaha......	140,452	63	4.5	Missouri River
32. Columbus....	88,150	38	4.3	Surface-water and wells
33. Providence...	132,146	53	4.0	Pawtuxet River
34. Kansas City..	132,716	53	4.0	Missouri River
35. Rochester....	133,896	53	3.9	Hemlock and Candice lakes
36. Evansville ...	50,756	20	3.9	Ohio River

TYPHOID FEVER DEATH-RATES AND WATER-SUPPLIES OF CITIES.—(*Continued.*)

City.	Population.	Deaths from Typhoid Fever. Total.	Deaths from Typhoid Fever. Per 10,000 living.	Water-supply.
37. Boston.......	448,477	174	3.9	Impounding reservoirs
38. Toledo.......	81,434	29	3.6	Maumee River
39. Cambridge...	70,028	24	3.4	Impounding reservoir
40. St. Louis.....	451,770	145	3.2	Mississippi River
41. Scranton.....	75,215	24	3.2	Impounding reservoir
42. Buffalo.......	255,664	80	3.1	Niagara River
43. Milwaukee...	204,468	61	3.0	Lake Michigan
44. New Haven..	81,298	22	2.7	Impounding reservoir
45. Worcester....	84,655	22	2.6	Impounding reservoir
46. Paterson.....	78,347	20	2.6	Passaic River (higher up)
47. Dayton......	61,220	15	2.5	Wells [ervoirs
48. Brooklyn....	806,343	194	2.4	Wells, ponds, and impounding res-
49. New York....	1,515,301	348	2.3	Impounding reservoir
50. Syracuse.....	88,143	18	2.0	Impounding reservoir and springs
51. New Orleans..	242,039	45	1.9	Mississippi River
52. Detroit.......	205,876	40	1.9	Detroit River
53. Lynn........	55,727	9	1.6	Impounding reservoir
54. Trenton......	57,458	9	1.6	Delaware River
London......	4,306,411	719	1.7	Filtered Thames and Lea rivers,
Glasgow.....	667,883	138	2.0	Loch Katrine [and $\frac{1}{6}$ from wells
Paris........	2,424,705	609	2.5	Spring water
Amsterdam ..	437,892	69	1.6	Filtered dune-water
Rotterdam...	222,233	12	.5	Filtered Maas River
Hague.......	169,828	3	.2	Filtered dune-water
Berlin.......	1,714,938	161	.9	Filtered Havel and Spree rivers
Hamburg....	634,878	115	1.8	Filtered Elbe River
Breslau.....	353,551	37	1.1	Filtered Oder River
Dresden.....	308,930	14	.5	Ground-water
Vienna.......	1,435,931	104	.7	Spring-water

The following table, compiled by G. W. Fuller, is worthy of study. The Cochituate water-supply was introduced into Boston in 1848, and, since its introduction, very much has been done to increase its purity. The change for the better is very marked, judging from the death-rate.

TABLE SHOWING DEATH-RATES FROM TYPHOID FEVER IN BOSTON, 1846–1892.

Years.	Deaths per 10,000 Inhabitants.
1846–49	17.4
1850–54	8.2
1855–59	5.0
1860–64	5.7
1865–69	5.6
1870–74	7.6
1875–79	4.2
1880–84	4.9
1885–89	4.1
1890–92	3.2

In the State of Connecticut the typhoid statistics for the past 35 years show a continual improvement, which must be due, at least in part, to abolition of old private wells for new and better water-supply. The percentage of deaths (for the entire state) from typhoid to total deaths from known causes stands as follows:

Average for the five years	1855–60	4.99 per cent.
" " " " "	1860–65	5.86 " "
" " " " "	1865–70	5.80 " "
" " " " "	1870–75	4.69 " "
" " " " "	1875–80	2.77 " "
" " " " "	1880–85	2.25 " "
" " " " "	1885–90	2.21 " "
For	1893	1.84 " "

Some very interesting statistics, compiled for the Massachusetts Board of Health by Mr. H. F. Mills,* show how greatly the typhoid death-rate is improved in towns by a change from the domestic well system to that of a public supply.

* Mass. Board of Health, 1890.

CHANGE IN THE DEATH-RATE FROM TYPHOID FEVER PER 10,000 INHABITANTS IN THE CITIES OF MASSACHUSETTS WHICH INTRODUCED WATER-SUPPLIES FROM 1867 TO 1876.

	Annual Average, 1859–68.	Date of Water-supply.	Annual Average, 1878–89.	Per Cent of Former.
1. Holyoke......	6.73	1873	8.93	133
2. Lawrence......	8.34	1875	8.33	100
3. Lowell.........	6.16	1872	7.63	124
4. Fall River.....	7.78	1874	6.32	81
5. Springfield.....	9.67	1875	5.29	55
6. Taunton.......	6.12	1876	5.02	82
7. Northampton...	10.98	1871	4.04	37
8. Lynn..........	9.06	1871	3.87	43
9. New Bedford ..	7.77	1869	3.80	49
10. Newton........	6.57	1876	3.65	56
11. Malden........	8.04	1870	3.54	44
12. Fitchburg......	10.59	1872	3.16	30
13. Woburn	8.29	1873	2.95	36
14. Somerville.....	4.28	1867	2.95	69
15. Chelsea........	5.97	1867	2.89	48
16. Waltham......	8.12	1873	2.42	30

For the entire state the rates are as follows:

DEATHS FROM TYPHOID FEVER IN MASSACHUSETTS DURING TWENTY YEARS.

Year.	Total Deaths.	Rate per 10,000 Population.	Percentage of Typhoid Deaths to Total Deaths.
1873....................	1406	8.9	4.15
1874....................	1147	7.1	3.6
1875....................	1059	6.4	3.02
1876....................	881	5.3	2.65
1877....................	814	4.8	2.59
1878....................	679	3 9	2.16
1879....................	637	3.6	2.00
1880....................	882	4.9	2.50
1881....................	1072	5.9	2.94
1882	1079	5.8	2.93
1883....................	860	4.6	2.28
1884....................	875	4.6	2.36
1885....................	768	3.9	2.02
1886....................	800	4.0	2.15
1887....................	922	4.5	2.26
1888....................	943	4.5	2.24
1889....................	891	4.1	2.13
1890....................	835	3.7	1.92
1891....................	821	3.6	1.82
1892....................	827	3.5	1.69

In considering the foregoing table, it must be remembered that the cities of Lawrence and Lowell draw their supplies from the Merrimac River at points where the sewage contamination is so gross that no improvement whatever could be expected from the introduction of such water in the raw state, and that at Holyoke the wide use of a polluted canal-water largely neutralizes the benefits resulting from the purer city supply. If these three cities be omitted from consideration, then the average annual typhoid death-rates, for the remaining thirteen, during the stated periods, before and after the introduction of public water, would be:

Before introduction of public supply, 7.94 per 10,000.
After introduction of public supply, 3.83 "

This is a showing which is very encouraging, and which effectually answers the frequently recurring question, "How was it our fathers got along so well without all these so-called modern improvements?"

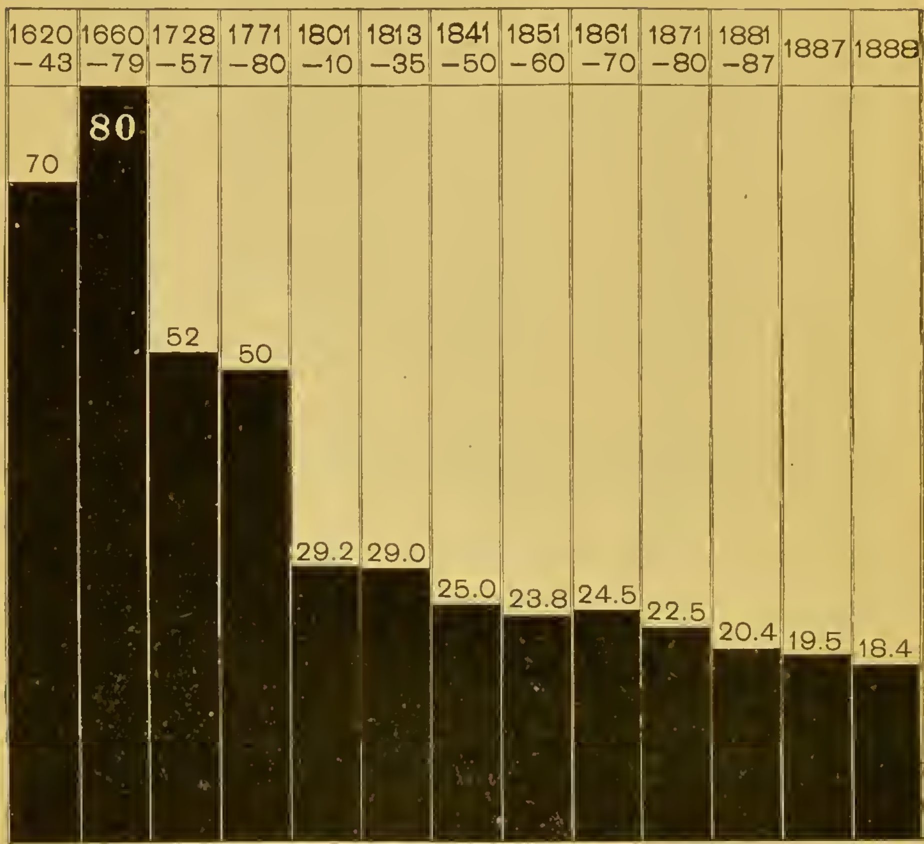
Such figures as the above, and others like them that might be quoted, stand in evidence that the question is a begged one, and that our progenitors were not so well off as many people fancy.

In illustration of just this point, it is instructive to note the statistics given for the total death-rate of London, by Dr. Lyon Playfair, at the Social Science Congress held at Glasgow in 1874:

Period.	Death-rate per 1000.
1660–79	80.0
1681–90	42.1
1746–55	35.5
1846–55	24.9
1871	22.6

The same statistics, but more extended, are given

graphically in the report of the State Board of Health of Michigan, and are here inserted:



DEATHS IN LONDON FROM ALL CAUSES PER 1000 POPULATION PER ANNUM IN PERIODS REPESENTING THE 17TH, 18TH AND 19TH CENTURIES.

At the time of the author's visit to Vienna in 1874, the typhoid death-rate was averaging about 11.5 per 10,000

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* The average annual typhoid death-rate per 10,000, for the five years ending May, 1893, for the following cities situated upon the Merrimac river (in the order named) is given by the Massachusetts Board of Health, 1892, as—

Concord, N. H.	3.88
Manchester, N. H.	2.95
Nashua, N. H.	4.77
Lowell, Mass.	10.66
Lawrence, Mass.	12.72
Haverhill, Mass.	3.63
Newburyport, Mass.	3.60

At the time only Lowell and Lawrence used river-water.

inhabitants. Pure water from the mountains was shortly afterwards introduced to replace the old wells, and the rate has now fallen to considerably less than 2.

In the course of an excellent article on "Hygiene of Public Water-supply," embodied in a report on the condition of the joint water-supplies of Pittsburgh and Allegheny, and published February, 1894, Dr. E. G. Matson makes the following comparison: "Consumption is fatal at nearly the same period of life as typhoid fever, which obviates to a great extent the errors which arise when the ages of the populations are left out of account. The following table shows the importance of typhoid fever as a cause of death at the beginning of adult life in three cities, compared with consumption. At this period typhoid fever is the most important single cause of death in Pittsburgh and Allegheny.

1890.	Percentage of Total Deaths, 20-29.		Deaths in 10,000 Living at all Ages.	
	Typhoid Fever.	Consumption.	Typhoid Fever.	Consumption.
Pittsburgh.......	27.6	19.5	13.2	14.7
Allegheny.......	38.1	24.8	17.1	14.4
Paris............	4.9	59.1	3.2	49.0

"The strong contrast between the prevalence of a disease which water does not influence and typhoid fever, which finds its surest line of attack through water, points plainly to the greatest sanitary defect of our cities."

Considering that it is usual to allow the deaths from typhoid fever to represent ten per cent. of the actual number of cases, the prevalence of the disease in Pittsburgh and Allegheny is certainly very pronounced.*

* Allegheny and a portion of Pittsburgh are supplied from the polluted Allegheny River.

The epidemic at Providence, R. I., in Nov. 1888, was traced to typhoid pollution entering the river at a point 3½ miles above the pumping station. Typhoid bacilli were found by Prudden and Ernst in the private filters of the Providence houses.

As showing the exceeding difference between care and no care in the selection of water for potable supply, the following quotation is taken from a report by Dr. Simmons, of the Yokohama Board of Health, covering certain features of the water question in India:

"The drinking-water supply is derived from wells, so-called 'tanks' or artificial ponds, and the water-courses of the country. The wells generally resemble those in other parts of Asia. The tanks are excavations made for the purpose of collecting the surface-water during the rainy season and storing it up for the dry. Necessarily they are mere stagnant pools. The water is used not only to quench thirst, but is said to be drunk as a sacred duty. At the same time, the reservoir serves as a large washing-tub for clothes, no matter how dirty or in what soiled condition, and for personal bathing. Many of the water-courses are sacred; notably the Ganges, a river 1600 miles long, in whose waters it is the religious duty for millions, not only for those living near its banks, but of pilgrims, to bathe and to cast their dead. The Hindoo cannot be made to use a latrine. In the cities he digs a hole in his habitation; in the country he seeks the fields, the hill-sides, the banks of streams and rivers when obliged to obey the calls of nature. Hence it is that the vicinity of towns and the banks of the tanks and water-courses are reeking with filth of the worst description, which is of necessity washed into the public water-supply with every rainfall. Add to this the misery of pilgrims, their poverty and disease, and their terrible crowding into the numerous towns which contain some temple or shrine, the object of their devotion, and we can see how India has become and remains the hot-bed of the cholera epidemic. In the United States official report, the horrors incident upon the pilgrimages are detailed with appalling minuteness. W. W. Hunter, in his Orissa, states that 24 high festivals

take place annually at Juggernaut. At one of them, about Easter, 40,000 persons indulge in hemp and hasheesh to a shocking degree. For weeks before the car festival in June and July, pilgrims come trooping in by thousands every day. They are fed by the temple cooks to the number of 90,000. Over 100,000 men and women, many of them unaccustomed to work or exposure, tug and strain at the car until they drop exhausted and block the road with their bodies. During every month of the year a stream of devotees flows along the great Orissa road from Calcutta, and every village for three hundred miles has its pilgrim encampments. The people travel in small bands, which at the time of the great feasts actually touch each other. Five-sixths of the whole are females, and ninety-five per cent. travel on foot, many of them marching hundreds and even thousands of miles, a contingent having been drummed up from every town or village in India by one or other of the three thousand emissaries of the temple, who scour the country in all directions in search of dupes. When those pilgrims who have not died on the road arrive at their journey's end, emaciated, with feet bound up in rags and plastered with mud and dirt, they rush into the sacred tanks or the sea, and emerge to dress in clean garments. Disease and death make havoc with them during their stay; corpses are buried in holes scooped in the sand, and the hillocks are covered with bones and skulls washed from their shallow graves by the tropical rains. The temple kitchen has the monopoly of cooking for the multitude, and provides food which, if fresh, is not unwholesome. Unhappily, it is presented before Juggernaut, so becoming too sacred for the minutest portion to be thrown away. Under the influence of the heat it soon undergoes putrefactive fermentation, and in forty-eight hours much of it is a loathsome mass, unfit for human food. Yet it forms the chief sustenance of the pil-

grims, and is the sole nourishment of thousands of beggars. Some one eats it to the very last grain. Injurious to the robust, it is deadly to the weak and wayworn, at least half of whom reach the place of suffering under some form of bowel complaint. Badly as they are fed, the poor wretches are worse lodged. Those who have the temporary shelter of four walls are housed in hovels built upon mud platforms about four feet high, in the centre of each of which is the hole which receives the ordure of the household, and around which the inmates eat and sleep. The platforms are covered with small cells without any windows or other apertures for ventilation, and in these caves the pilgrims are packed, in a country where, during seven months out of the twelve, the thermometer marks from 85 to 100 degrees Fahr. Hunter says that the scenes of agony and suffocation enacted in these hideous dens baffle description. In some of the best of them, 13 feet long by 10 feet broad and 6½ high, as many as 80 persons pass the night. It is not, then, surprising to learn that the stench is overpowering and the heat like that of an oven. Of 300,000 who visit Juggernaut in one season, 90,000 are often packed together for a week in 5,000 of these lodgings. In certain seasons, however, the devotees can and do sleep in the open air, camping out in regiments and battalions, covered only with the same meagre cotton garment that clothes them by day. The heavy dews are unhealthy enough; but the great festival falls at the beginning of the rains, when the water tumbles in solid sheets. Then lanes and alleys are converted into torrents or stinking canals, and the pilgrims are driven into the vile tenements. Cholera invariably breaks out. Living and dead are huddled together. In the numerous so-called corpse-fields around the town as many as forty or fifty bodies are seen at a time, and vultures sit and dogs lounge lazily about gorged with human flesh. In fact, there is no end to the recurrence of

incidents of misery and humiliation, the horrors of which, says the Bishop of Calcutta, are unutterable, but which are eclipsed by those of the return journey. Plundered by priests, fleeced by landlords, the surviving victims reel homeward, staggering under their burdens of putrid food wrapped up in dirty clothes, or packed in heavy baskets or earthenware jars. Every stream is flooded, and the travelers have often to sit for days in the rain on the bank of a river before a boat will venture to cross. At all these points the corpses lie thickly strewn around (an English traveler counted forty close to one ferry), which accounts for the prevalence of cholera on the banks of brooks, streams, and rivers. Some poor creatures drop and die by the way; others crowd into the villages and halting-places on the road, where those who gain admittance cram the lodging-places to overflowing, and thousands pass the night in the streets, and find no cover from the drenching storms. Groups are huddled under the trees; long lines are stretched among the carts and bullocks on the roadside, their hair saturated with the mud on which they lie; hundreds sit on the wet grass, not daring to lie down, and rocking themselves to a monotonous chant through the long hours of the dreary night. It is impossible to compute the slaughter of this one pilgrimage. Bishop Wilson estimates it at not less than 50,000. And this description might be used for all the great Indian pilgrimages, of which there are probably a dozen annually, to say nothing of the hundreds of smaller shrines scattered through the peninsula, each of which attracts its minor hordes of credulous votaries. So that cholera has abundant opportunities for spreading over the whole of Hindostan every year by many huge armies of filthy pilgrims; and the country itself well deserves the reputation it universally possesses of being the birthplace and settled home of the malady.

With the Chinese it is quite different. "Although their

country is in closest proximity to India, and of much greater extent and twice as populous, you will find that cholera is comparatively rare. The drinking-water supply of China is derived from wells, springs, and natural streams. Now, though the wells and springs are used in China for drinking purposes to much the same extent and in much the same manner as in India, yet the rivers and lakes are not drunk from as a part of a religious duty, nor is bathing in them a sacred rite. The absence of pilgrimages contributes to keep the water comparatively uncontaminated.

"Human manure is valuable and hoarded for fertilizing purposes. Hence, the excreta are deposited by the individual in a receptacle made for the express purpose, and from motives of economy kept in a fairly good condition of repair. Even in cities and large towns latrines are not employed. Special wooden boxes are among the first necessities of bedroom furniture, and form part of every bridal outfit. The contents are daily emptied into earthen jars or wooden tubs placed in the court-yard of the house, whence they are removed by the scavenger either direct to the fields, or to boats destined to convey them to a distance. Thus the greatest amount of security attainable is provided against the contamination of the water-supply from this source. A still more potent preventive of infection is to be found in the fact that the Chinese will always, if possible, boil water before drinking it, even if they are unable to make it in to some kind of tea. Here it is easy to see in the contrast between the customs of the Hindoo on the one hand and the Chinese on the other, how in the one case every possible facility is provided for the propagation of infection; in the other, how the danger of contamination is reduced to a minimum."

This statement concerning China is hardly in accord with the following naval report:

"In Japan and China the close relation of the food and

water-supply with the excreta not only illustrates the ætiology of cholera, but, at the same time, shows what small prospect there is of its extermination. In Japan the soil is tilled in absolute contiguity to the wells, and is fertilized with liquefied human excreta. Dr. Jameson, a physician of Shanghai, cites an instance where, under a spigot, he saw the rice for the daily food being washed at the same time with a vessel just emptied of cholera discharges." *

Illustrations such as have been given, showing the power of water to carry specific disease, could be very greatly multiplied, and detailed reference could be made to the celebrated epidemics of typhoid at Florence, Italy; Caterham, England; and Lowell and Lawrence, Mass. But, while passing these instances with the simple statement that they were all traceable to polluted drinking-water, it is well to pause for a moment to consider what may be learned from the terrible outbreak of cholera at Hamburg, Germany, in 1892.

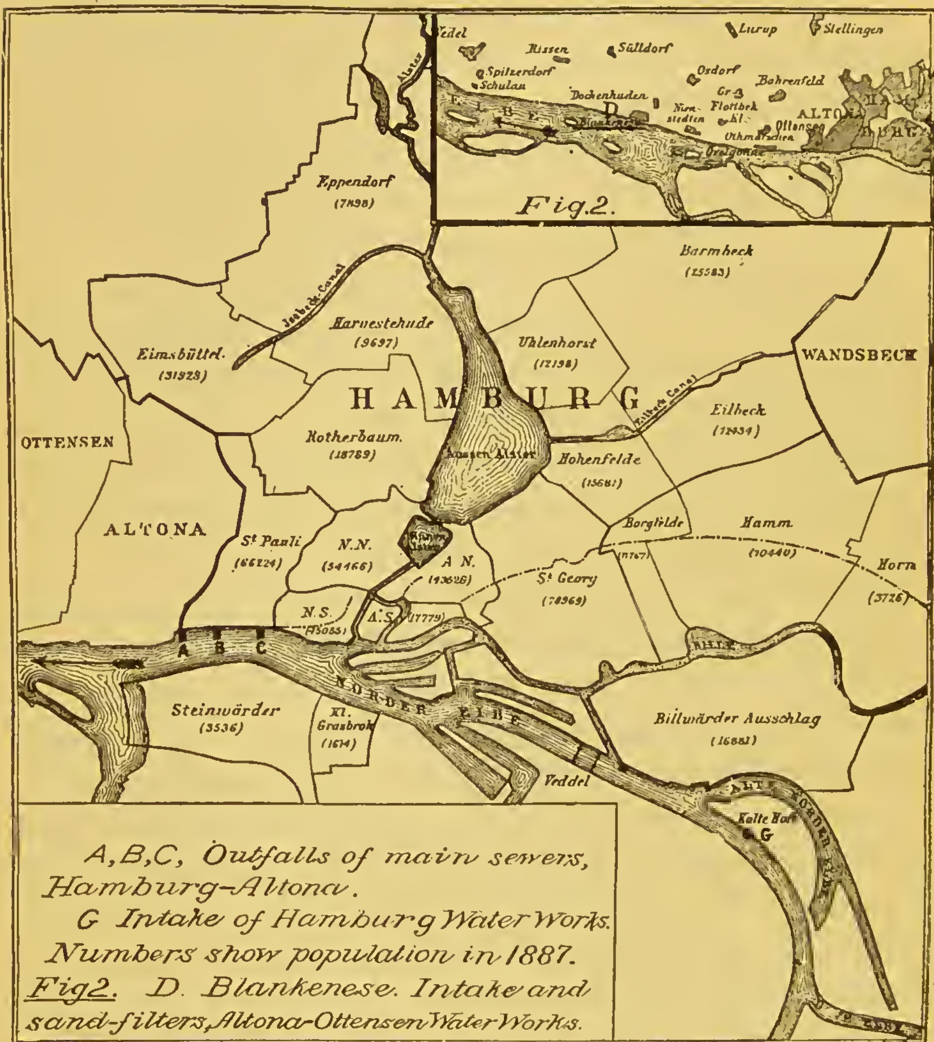
The city had at that time a population of 640,400. In the official tabulation, the epidemic is noted as having lasted from August 16th to November 12th, although 42 deaths appear to have taken place in the next month (December) and 20 in January, 1893. The total number of cholera cases reported during that time was 17,020, with a total death-list of 8,605, a mortality percentage of 50.05.

By months the cases were:

August	7,427
September	9,341
October	181
November	7
December	42
January	20
February	1
March	1
	17,020

* Report of Surgeon-General U. S. Navy, 1892.

To a proper appreciation of the conditions of this epidemic, a study of the local map is essential.



AFTER REINKE AND SEDGWICK.

It will be observed that Altona (143,000 population), Hamburg (640,400 populaiton), and Wandsbeck (20,000 population), are practically one and the same town, separated by only imaginary boundaries, which a stranger could not locate. The three municipalities are, however, supplied with water from three different sources. Wandsbeck obtains filtered water from a lake unexposed to contamina-

tion; Hamburg pumps water from the Elbe river, and in 1892 the intake was situated just south of the city, but not far enough up stream to escape contamination from a recession of polluted water at flood tide. After some imperfect sedimentation, the water passed directly to the consumer without filtration. Altona, strangely enough, pumps its water from the Elbe at a point about eight miles below that at which the river receives the combined sewage of the three cities, with their population of over 800,000. Fortunately for Altona, this most grossly polluted supply is filtered with exceeding care before delivery to the people. Further description of the Hamburg epidemic can best be given in the words of Dr. Thorne, medical officer of the London local Government Board.*

"The different behavior of Hamburg and Altona as regards cholera is extremely interesting in this connection. The two towns adjoin; they are practically one city. The division between the two is no more obvious than that between two densely-peopled London parishes, and yet a spot-map indicating the houses which were attacked with cholera, which was shown to me by Professor Koch, points out clearly that whereas the disease prevailed in epidemic form on the Hamburg side of the boundary line, that line, running in and out among the streets and houses and at times passing diagonally through the houses themselves, formed the limit beyond which the epidemic as such did not extend. The red dots on one side of the dividing line were proof of the epidemicity of cholera in Hamburg; their comparative absence on the Altona side of it was proof of the absence of an epidemic in Altona. To use Professor Koch's own words: 'Cholera in Hamburg went right up to the boundary of Altona and there stopped. In one street, which for a long

* "Cholera Prospects and Prevention," London, 1893.

way forms the boundary, there was cholera on the Hamburg side, whereas the Altona side was free from it.' And yet there was one detectable difference, and one only, between the two adjacent areas—they had different water-services.

"Professor Koch has collected certain proofs which he regards as crucial on this point, and Dr. Reincke has supplied me with a small plan in support of the contention. At one point close to and on the Hamburg side of the boundary line between Hamburg and Altona is a large yard known as the Hamburger-Platz. It contains two rows of large and lofty dwellings, containing seventy-two separate tenements and some 400 people, belonging almost wholly to those classes who suffered most from cholera elsewhere in Hamburg. But whilst cholera is shown by the spot-map to have prevailed all around, not a single case occurred amongst the many residents of this court during the whole epidemic. And why? Professor Koch explains that owing to local difficulties water from the Hamburg mains could not easily be obtained for the dwellings in question, and hence a supply had been laid on from one of the Altona mains in an adjacent street. This was the only part of Hamburg which received Altona water, and I am informed that it was the only spot in Hamburg in which was aggregated a population of the class in question which escaped the cholera. At the date of my visit to Hamburg a notice-board was affixed at the entrance of this court. It stated that certain tenements were to let; but above all, in large type, and as an inducement to intending tenants, was the announcement that the court was not only within the jurisdiction of Hamburg, with the privileges still attaching to the old Hanseatic cities, but that it had a supply of Altona water."

During this epidemic the deaths in the several cities were:

	Population.	Deaths.	Deaths per 10.000 Inhabitants.
Hamburg	640,400	8605	134.4
Altona	143,000	328	23.0
Wandsbeck	20,000	43	22.0

"That infectious matter was communicated to the Elbe water from Hamburg is not in any way a hypothesis. Cholera germs had been as a fact found in the Elbe water. They were found a little below the place where the Hamburg main sewer flows into the Elbe. They were also found in one of the two (Altona) basins into which the water flowed before filtration." *

The following analysis of the Hamburg public supply from the Elbe river, during the cholera epidemic of 1892, is given in *Chemical News*, LXVI., 144:

Appearance	Turbid and very yellow
Taste	Slightly unpleasant
Odor	Extremely small
Deposit	Small and dirty-looking
Chlorine	472.000 per million
Free ammonia	1.065 " "
Albuminoid ammonia	0 293 " "
Nitrates	26.430 " "
Required oxygen (15 minutes)	0.928 " "
" " (4 hours)	3.428 " "
Total solids	1160.700 " "

To the sanitarian or engineer, who purposes dealing with the question of public water-supply, some knowledge of the ætiology of the two prominent water-borne diseases, "cholera" and "typhoid fever," is essential to the proper and successful fulfilling of his professional responsibilities.

* Koch, *Zeit. für Hygiene und Infect.-Krank.*, xiv.

The cholera "germ" (*spirillum choleræ Asiaticæ*), or "comma bacillus," was discovered by Koch in 1884 in the excreta of cholera patients and in the intestinal contents of those dead of the disease.

The spirillum will grow in ordinary culture jelly at the usual room temperature, forming in twenty-four hours small white colonies which increase in size and finally entirely liquefy the gelatine. Growth is arrested if the temperature exceed 107° F., or if it fall below 59° F.

In shape it is not unlike the "comma" whence it derives its name, and the union of two or more attached end to end often causes the appearance of semicircles, S-shaped figures, and long spiral filaments. In size the "germ" varies from 0.8 to 2 microns in length, and from 0.3 to 0.4 in breadth. It is generally conceded that the cholera spirillum does not form spores, a characteristic which permits of its ready destruction by heat, a "spore" being much more difficult to destroy than a full-grown bacterium. Sternberg found the thermal death-point to be 52° C. (125.6° F.), the time of exposure having been four minutes, and, although a slightly higher figure has been recorded, by other investigators, there is no question but that the degree of heat required is very low.

"In a moist condition this spirillum retains its vitality for months. Koch found in his early investigations that rapid multiplication may occur upon the surface of moist linen, and also demonstrated its presence in the foul water of a tank in India which was used by the natives for drinking purposes. It is quickly destroyed by dessication, as first determined by Koch, who found that it did not grow after two or three hours, when dried in a thin film on a glass cover." If the thickness of the film be considerable, or if the drying take place on silk threads, the vitality may remain for some weeks. (Kitasato.)

Viability of the Cholera Spirillum in Water.

(Babes, 1884-85.) Found the organisms alive after seven days in Seine water.

(Wolffhügel, 1886.) The germ may live fifteen to twenty days in unsterilized tap-water. He repeatedly found it alive after three months, and believes this due to what has been termed acclimatization. Rarely the organisms die in the first few days. After five to seven days they are many times more numerous than in the primary inoculation.

(Karliniski, 1889.). Found the organism dead after two or three days in unsterilized spring water.

(Hockstetter, 1887.) The organism lives indefinitely in unsterilized tap-water even when the water contains large numbers of other organisms. He found the germs alive after an interval of 392 days.

(Nicati and Rietsch, 1885.) Found the spirillum alive in sterilized distilled water after twenty days. In sterilized water from the Port of Marseilles after eighty-one days. In Marseilles canal-water, thirty-eight days. In sea-water, sixty-four days. In bilge-water from an iron steamship *en route* from Japan, thirty-two days.

Stoddart finds that there is no antagonism between the cholera spirillum and ordinary water organisms. He has kept it alive for weeks in both pure and polluted waters.

According to Kitasato the germs of typhoid and cholera are more hardy than bacteria of putrefaction. On the other hand, Esmarch found that pathogenic germs in dead bodies were quickly killed by putrefactive bacteria. According to Giaxa, cholera germs quickly died in water containing many other bacteria, and typhoid germs also died, but less quickly. Schiller found that cholera germs lived 14 days in a mixture of excrement and urine, and for 13 days in Berlin sewage. Cunningham found cholera germs lived 4 to 5 days in clear

water at room temperature, and in dirty water 4 to 9 days. In the latter water, previously boiled, the germs lived 25 days. In garden earth, 10 to 26 days. In same earth mixed with fæcal material, 6 to 9 days. In same mixture of earth and fæcal matter previously cooked—*i.e.*, sterilized —47 days.

Gruber and von Kerner show the power of the cholera germ to remain alive in river-water, and in that of the Vienna city supply, for seven days.

Sternberg believes that increase of either the cholera spirillum or the typhoid bacillus in ordinary water is unlikely to occur, owing to the interfering action of the common water bacilli.

According to Boer and Bolton the cholera spirillum is killed by a two-hours' exposure to the following solutions: hydrochloric acid, 1:1350; sulphuric acid, 1:1300; caustic soda, 1:150; ammonia, 1:350; mercuric cyanide, 1:60,000; silver nitrate, 1:4000; arsenite of soda, 1:400; malachite green, 1:5000; methyl violet, 1:1000; carbolic acid, 1:400; mercuric chloride, 1:10,000; blue vitriol, 1:500.

"Experiment has shown the spirillum to be very sensitive to the action of acids,* and to be quickly destroyed by the acid secretions of the stomach, of man or the lower animals, when the functions of this organ are normally performed."

"The spirillum is not found in the blood nor in the various organs of individuals who have succumbed to an attack of cholera, but it is constantly found in the alvine

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* Stutzer states that a solution of .05 per cent of sulphuric acid is fatal to the cholera spirillum in fifteen minutes, and a .02 per cent solution kills in twenty-four hours. He found that iron pipes could be disinfected by sulphuric acid without the metal being sensibly attacked, and estimates that 100 kilos of 60° B acid (1 lb. of acid to 40 imp. gallons of water) would disinfect 40,000 litres of water at an expense for acid of about 18 cents per 100 imp. gallons of water treated. (Rideal.)

discharges during life and in the contents of the intestine examined immediately after death. It is evident, therefore, that the morbid phenomena must be ascribed to the absorption of toxic substances formed during its multiplication in the intestine. As a rule the spirillum is not present in vomited matters."

"The most satisfactory evidence that this spirillum is able to produce cholera in man is afforded by an accidental infection which occurred in Berlin, in the case of a young man who was one of the attendants at the Imperial Board of Health when cholera cultures were being made for the instruction of students." *

An entirely similar case came under the writer's observation, in Paris, while attending the course at the Pasteur Institute. One of the students, an Italian, was in the habit of constantly smoking cigarettes while at work. He became inoculated with Asiatic cholera through laying down his cigarette in contact with a cholera preparation. He took the typical disease and recovered. A friend of the author's reports a like instance of infection, observed by him while a student in Koch's laboratory.

Pettenkoffer and Emmerich each swallowed pure cultures of the comma bacillus, with the result of producing only temporary diarrhœa, and they thereupon claimed that the germ is not to be considered as the cause of cholera. As opposed to this, Roux points out that the pure cultures referred to above may have been attenuated and very far from the point of virulence. Moreover, he shows that, even when truly virulent cultures are swallowed, the disease does not surely result. The author was informed that this point was recently covered at the Pasteur Institute by the swallowing of virulent germs from the same culture, by

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* Sternberg's "Manual of Bacteriology," 1893.

Roux, Metchnikoff, and two others. Of these four, three had diarrhœa and one had typical Asiatic cholera.

The President of the National Health Society of England says in a recent address: "We may lay aside all pedantry and mystery-talk of epidemic constitution, pandemic waves, telluric influences, cholera blasts, cholera clouds, blue mists, and the like terms of art with which an amiable class of meteorologists has delighted to cloak their ignorance. Cholera is a filth disease carried by filthy people to filthy places. It only develops where it finds dirty places, and the dirty habit of drinking polluted water and living on a polluted soil. Cholera does not travel by air-waves or blasts. We drink cholera and we eat cholera, but we cannot catch cholera as we catch measles, scarlatina, or whooping-cough."

"In India, where the water for domestic purposes is empounded in open excavations in the ground, like those near brickyards in this country; in India, where the people wash their soiled clothing by the side of these same tanks, and allow the waste water to flow back into them in innocent disregard of all sanitary laws; in India, where the people deposit all ordure on the surface of the ground, not having in most cases even the pretense of a pit or cesspool; in India, where the people drink the water in which they have just bathed, cholera is never absent. It is not necessary to invoke the currents of the air to explain the constant occurrence, or the terrible virulence of the disease. And yet, in this same India, the people who are brought under the civilization of the West, through the labor of the Christian missionaries, and who adopt new modes of living with their change of religion, escape the cholera as completely as if there were no such disease.

"Cholera is always carried. It never travels on its own account or by its own conveyance, and it is not half so

bad a disease as it has been painted by a frightened public.

"It is stated on the authority of the head nurse, that not a single case of cholera originated in the hospital of Hamburg during the recent epidemic in that city, though the sick were often placed two in the same bed and the dead in long rows. Amid the gloom and excitement, scores of suspects were hurried off to the hospital who were afterwards found to be suffering from some other disease. Not one of these persons contracted the disease from the cholera patients with whom they were forced to associate. It would seem as if the safest place at the time of a great epidemic of cholera would be where there is the most sickness. All of these statements point to the fact that cholera is not infectious, and that the danger has been very greatly over-estimated." *

The bacillus of typhoid fever was first described by Eberth in 1880, and more recent investigations tend to confirm the belief in its ætiological relation to the disease.†

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* *British Medical Journal.*

† The following observers report the discovery of the typhoid bacillus in water, strongly suspected of having caused typhoid fever:

Widal. *Gazette heb. Med. et Chir.*, 1887, 146.
Moers. *Centralblatt f. allgem. Gesundheit*, II. 144.
Kamen. *Centralblatt f. Bakteriologie*, XI. 32.
Beumer. *Deutsche med. Wochenschrift*, 1887, No. 28.
Henrijean. *Annal. Micrographie*, II. 401.
Fodor. *Centralblatt f. Bakteriologie*, XI. 121.
Péré. *Annal Inst. Pasteur*, V. 79.

It is interesting to note that recent investigations have shown that common flies may aid in distributing the disease, inasmuch as the cholera germs are not killed by passing through their digestive organs.

"Pettenkofer has given the key to the whole situation by saying that filth is like gunpowder, for which cholera is a spark. A community had better remove the gunpowder than try to beat off the spark; for in spite of their efforts, however frantic, this may at any time reach the powder, and if it does, is sure to blow them to pieces." (SEDGWICK.)

"Pathologists are disposed to accept this bacillus as the veritable 'germ' of typhoid fever, notwithstanding the fact that the final proof that such is the case is still wanting. This final proof would consist in the production in man, or in one of the lower animals, of the specific morbid phenomena which characterize the disease in question, by the introduction of pure cultures of the bacillus into the body of a healthy individual. Evidently it is impracticable to make the test upon man, and thus far we have no satisfactory evidence that any one of the lower animals is subject to the disease as it manifests itself in man." *

Since the writing of this passage by Sternberg, much work has been done, by Sanarelli, upon aritficial typhoid fever, and he has shown that the disease is capable of ready transmission to animals (see Annales de l'Institute Pasteur). "The period of collapse, that is to say, the last phase of the typhoid infection, is what we produce experimentally in animals. With them the typhoid poison manifests itself too quickly to permit the resistance of the organism to express itself as fever during the early stages of intoxication. If the Eberth bacillus could produce its toxin in the human organism with the same intensity that the germs of cholera produce theirs, typhoid fever would become, like cholera, a malady both short and apyretic." (Sanarelli.)

The typhoid bacillus is usually one to three microns long and from 0.5 to 0.8 micron broad. Its ends are rounded. Growth readily takes place at ordinary temperatures in culture media, and the colonies do not liquefy the gelatine. Spores are not produced. In inoculated milk it develops

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* Sternberg's "Manual of Bacteriology."

abundantly, a property which has been productive of many serious outbreaks of the disease.*

The "germ" is capable of maintaining its existence quite independent of the living animal body, as was proven by Fränkel and Simmonds, who showed that it multiplied in the spleen after death. "This does not in any way weaken the evidence as to the ætiological *rôle* of the bacillus, but simply shows that dead animal matter is a suitable *nidus*." (Sternberg.)

Blythe also considers its probable normal existence that of a saprophyte—*i.e.*, an organism subsisting on decaying organic material.†

There are those who believe, and it is a very conceivable belief that the progenitor of the typhoid bacillus is often a saprophyte, which takes on its pathogenic properties by cultivation through successive generations, under favorable conditions as to light and temperature, and amid suitable

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* For a list of thirty-six epidemics of typhoid, traceable to a polluted milk-supply, see *Engineering Record*, April 28, 1894.

Also a description of the more recent outbreak at Montclair, N. J.—*Engineering News*, April 19, 1894.

Such cases commonly arise from washing milk-cans with water confessedly impure, but "thought to be good enough to wash cans with."

"I spoke of milk as a favorite medium for the growth of the cholera spirillum. Milk has also served as a vehicle for conveying the infection of that disease. In 1887 an outbreak of cholera occurred on board the Ardenclutha, moored in the Ganges, and, by a process of elimination, Dr. W. J. Simpson, health officer for Calcutta, succeeded in tracing the disease to the use of a certain milk-supply. Fourteen of the crew who had not partaken of this milk remained altogether free from sickness; whereas of ten who drank it, nine, or ninety per cent, sickened—four with fatal cholera, five with so-called 'diarrhœa'—the one who escaped having only drunk a 'thimbleful.' The milk being stopped, all sickness was stayed. In this case the milk—which was procured from a distance and had been brought on board by a native—was admittedly somewhat copiously diluted with the contents of a tank polluted by cholera excreta. Cases of cholera occurred amongst the natives using the tank water directly after the contamination took place, and this localized outbreak amongst them was simultaneous with that on board the Ardenclutha." (Thorne.)

† "Manual of Public Health."

filthy surroundings. Many illustrations are available, in the world of larger vegetables, of great changes in structure and properties due to cultivation under an altered environment. Isolated cases of typhoid may be thus accounted for where it would be difficult to suppose contagion from a previously existing case.

In a recent paper before the British Medical Association, Mr. H. R. Kenwood suggests the possibility of the typhoid bacillus being an evolution from the bacillus *coli communis*, an organism ever present in the intestines, and adds that greater changes may be artificially induced, both functional and morphological, in bacteria, than are represented by the slight differences between the bacilli in question.

Recent investigations by Sanarelli show, however, that the differences between the two bacilli covered by Kenwood's suggestion are really very great; but, while the bacteriologists search for further light upon the question of the ancestry of the typhoid germ, the evolution, or saprophyte, theory is a good working formula for the sanitarian, and upon it he should for the present rest, remembering that typhoid fever and filth are very closely related.

The great influence of light upon the growth of the typhoid germ has been demonstrated by Janowski, who found that freshly inoculated gelatine, if kept in the dark, developed colonies in three days; if placed in diffused daylight, growth occured in five days; but if the exposure were to direct sunlight, for six hours, the gelatine became sterile.

This inability to survive long exposure to sunlight is not peculiar to the typhoid bacillus.. Fortunately for us, such sterilizing action is of wide application, and is one of nature's chief lines of defence against overwhelming bacterial infection. A simple illustration, showing the inhibiting action of sunlight toward such common bacteria as liquefy

culture-jelly, may be readily made as follows: Pour some melted jelly, previously inoculated with a drop of broken-down culture medium, into a Petri dish, upon the bottom of which have been pasted letters cut from black paper. When the jelly has set, expose the inverted dish, for several hours, in a cool place, to the bright sunlight. After exposure, place the preparation in the dark, at the usual culture temperature (22° C.). Liquefaction will be found to take place only in the portions shaded by the paper, and the letters will be found sharply countersunk in the jelly.

ILLUSTRATING STERILIZING ACTION OF SUNLIGHT.

Burnett found that the water furnished to Colombo, in the island of Ceylon, although not of high quality from a chemical point of view, rarely contained more than two microbes per cubic centimetre. As the supply is from extensive, shallow surface-waters, the explanation is offered

that nearly complete sterilization results from prolonged exposure to the direct rays of the tropical sun.*

It is generally observed that the number of bacteria in river-water is less in summer than in winter, but it must not be hastily concluded that this is due entirely to the sterilizing action of light. As is shown upon another page, the summer feeders are commonly springs, while in winter much impure surface washing reaches the streams. Moreover, the action of light does not penetrate the water to any considerable depth.

Sternberg, and also Janowski, found the thermal death-point of the bacillus to be 56° C. (132.8° F.), the time of exposure having been ten minutes.

Typhoid bacilli are not destroyed by extreme cold. The epidemic at Plymouth, Pa., in 1885, is a case in point. As we have seen (page 33), the outbreak was traced to the dejecta of a single patient, which had been thrown upon the frozen ground and snow, during the early part of January, and which remained there until washed into the stream by the thaw occurring on March 26th. During this period the temperature had fallen to 22° F. below zero.†

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* *Chem. News*, LXX. 285.

† Very similar to the Plymouth outbreak is the one which occurred at Windsor, Vt., a town of some 2000 inhabitants, during the spring of 1894. The following is extracted from the newspaper account of the epidemic.

Several miles west of Windsor, and fully a mile from the reservoir which supplies the town with water, is a farm-house built on a hillside. About 200 feet below the house a brook tumbles down from a spring. The spring supplies the brook, and the brook supplies the reservoir which supplies Windsor with drinking-water. All the rain and snowfall of that hillside, upon which the farm-house stands, drains into the brook. In January a farmer's daughter was taken ill and for four weeks her prostration continued. A physician from the village attended the case, which he appears to have considered merely as a severe attack of the grip. It was not the grip at all; it was typhoid fever.

The patient's excreta went into the family privy vault on the hillside. That was in January, and everything was frozen solid. For several weeks the typhoid germs remained in the vault in a frozen state, without having their

Prudden found the germ capable of development after having been frozen in ice for over one hundred days, and he also made the interesting observation that alternate freezing and thawing proved fatal to it.

"The typhoid bacillus retains its vitality for many months in cultures. The writer has preserved bouillon cultures for more than a year in hermetically sealed tubes, and has found that development promptly occurred in nutrient gelatine inoculated from these. Dried upon a cover glass, it may grow in a suitable medium after having been preserved for eight to ten weeks. When added to sterilized distilled water it may retain its vitality for more than four weeks, and in sterilized sea-water for ten days. Added to putrefying fæces it may preserve its vitality for several months; in typhoid stools for three months; and in earth, upon which bouillon cultures had been poured, for five and one-half months." *

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potency in the least impaired. In March came a heavy thaw, and the melting snow swelled the brook, carrying the contents of the vault into the stream below; for, although the vault was deep, the side next the brook was left entirely open and there was nothing to keep the infectious germs in their prison with the snow-water of the hillside pouring down. The germs were carried into the reservoir under the ice, which was still many inches thick, and there, in the temperature of ice-water, they remained until the last of March, when they swept through the aqueduct down upon the unsuspecting town.

The suddenness with which Windsor was struck by this epidemic, and the rapidity with which the disease was spread, is a somewhat remarkable fact. The great majority of cases appeared between March 29 and April 4. They kept coming until April 7 by the half-dozen, and then there was a let-up. About 120 cases in all were reported to the health officer. Many, of course, were of a mild form, but there was no mistaking the disease. No one thought of calling it the grip. The epidemic hit all sorts of families, rich and poor, clean and unclean. The majority of patients were under 14 years of age, the youngest being 1½ years and the oldest a man 44 years of age. Both the infant and the middle-aged man died, making 13 in all.

Luckily the source of the contagion was soon discovered, for all the cases came in households using the aqueduct water for cooking or drinking purposes, while among families depending entirely upon well-water no typhoid appeared.

* Sternberg, "Manual of Bacteriology."

Theobald Smith states it to be generally admitted that the "disease germs found in water, rarely, if ever, increase in number, even if the water be polluted, and they finally die."

An experiment was undertaken at the Lawrence experiment station to determine the viability of the typhoid bacillus in water near the freezing point. After specific inoculation, the river-water was placed in a bottle surrounded with ice, and a portion was removed daily for examination, with the following results:

1st day	6120	germs per cubic centimeter
5th "	3100	" " " "
10th "	490	" " " "
15th "	100	" " " "
20th "	17	" " " "
25th "	0	" " " "

Some few survived until the twenty-fourth day.

"The longest time we have been able to keep the germs of typhoid fever alive in Merrimac River water is about three weeks; more commonly they disappear in one week. This short period of existence presents the probable reason why the fever may be readily carried down a river from city to city, while a polluted stream may enter one end of a large pond, whose waters are changed only after months, and a water-supply drawn from the opposite end may be continually free from the disease pollution." *

* Mills, Am. Soc. C. E. xxx. 364.

At a mill at Canton, Mass., in June, 1888, out of 120 men some 50 were taken with typhoid. The families of these men were not affected. The drinking-water of the mill was from a well on the opposite side of a ledge and 54 feet distant from a privy vault, which latter had received typhoid dejecta eight months previcusly. By experimenting with salt, direct connection by infiltration from vault was shown. Note the *time* element in this case.—J., New Eng. Water Works Asso. v. 150.

An odd instance of viability in bacteria is quoted by Dr. Baker of the Michigan Board of Health. It seems that a cannon ball, previously smeared with a culture of a specific germ, was fired through a cake of culture-jelly, and that colonies were afterwards developed in the medium.

It would appear that the conditions under which typhoid fever occurs obtain more frequently in the country than in large cities. This statement is hardly in accord with popular belief, but it has been proven true for Massachusetts, and a study of the following statistics will show it to be also true for the state of New York:

AVERAGE ANNUAL TYPHOID DEATH-RATE, PER 10,000 INHABITANTS.

For the whole State, for the five years 1888–92 .... 2.740

Typhoid death-rates for 1892, per 10,000 inhabitants:

For the largest six N. Y. cities		2.402
" " "rest of districts"		3.331
	Population per Square Mile.	
" " Maritime district	1400	2.000
" " Hudson Valley district	117	3.625
" " Adirondack & Northern dist.	26	2.324
" " Mohawk Valley district	80	4.758
" " Southern Tier "	60	2.852
" " East Central "	59	2.040
" " West Central "	65	2 000
" " Lake Ontario & Western dist.	174	3.540
" " whole State	130	2.566

The difference here observed must be largely due to the greater care exercised in the selection of a water-supply for a city, as compared with that so frequently displayed in the sinking of a country well. It would seem that a due saving of the steps of the housewife is all that the average farmer thinks about when selecting a site for his well, and he digs it in the most convenient position, and entirely without regard to local surroundings. The writer saw one domestic supply drawn from a tall pump, which was nearly covered by a manure heap of so great proportions that the pump-handle had to be extended by splicing a stick thereon in

order to permit of its being reached. The water was caught in a small trough extending over, and resting upon, the top of the manure pile.

The maintenance of the water-supply in a pure state, however, is not of itself enough to eliminate typhoid fever. The local hygienic conditions must be good as well, otherwise the resisting powers of the human organism will be lowered and left unable to oppose the invading germs, which may come from some other source.

In recent work by Sanarelli, conducted at the Pasteur Institute, Paris, this point is well covered. He shows that if animals are previously injected with the toxins of certain bacteria, such as *coli communis*, they afterwards succumb to inoculation with Eberth bacillus with complete symptoms of typhoid.

Other unfinished experiments point towards the obtaining of similar results, when the animals are inoculated with typhoid culture, after they have been compelled to breathe air laden with putrefactive materials for a certain time.

These results are very suggestive, and bear directly upon the relation of unsanitary surroundings and development of typhoid.*

From both experiment and experience, we are forced to conclude that "good water" and "clean surroundings" go hand in hand in protecting the people against typhoid fever and cholera. The following table was prepared by Dr. E. F. Smith, in support of this proposition:

* As tending in the same direction, Nocard and Roux "found by experiment that an attenuated culture of the anthrax bacillus, which was not fatal to guinea-pigs, killed these animals when injected into the muscles of the thigh after they had been bruised by mechanical violence. Charrin and Roger found that white rats, which are unsusceptible to anthrax, became infected and frequently died if they were exhausted, previous to inoculation, by being compelled to turn a revolving wheel. Pasteur found that fowls, which have a natural immunity against anthrax, become infected and perish if they are subjected to artificial refrigeration after inoculation." (Sternberg.)

TYPHOID AND CHOLERA IN BUDAPEST, 1863–77.

1. *Influence of filthy houses:*

Deaths from cholera per 100 houses when the interior of the DWELLING was	1. Very clean	92
	2. Clean	199
	3. Dirty	268
	4. Very dirty	402
Deaths from typhoid fever per 100 houses when the interior of the DWELLING was	1. Very clean	165
	2. Clean	177
	3. Dirty	182
	4. Very dirty	356

2. *Influence of filthy yards:*

Cholera deaths per 100 houses when the YARD was	1. Very clean	188
	2. Clean	214
	3. Dirty	263
	4. Very dirty	389
Typhoid fever deaths per 100 houses when the YARD was	1. Very clean	159
	2. Clean	186
	3. Dirty	208
	4. Very dirty	282

Another tabulation from the same source is here given.

MEAN ANNUAL DEATH-RATE IN UNSEWERED AND SEWERED CITIES IN RECENT YEARS.

	City.	Period Included.	Rate per 1000 Living.
Unsewered.	New Orleans	20 years, 1865–84	33.4
	Baltimore	15 years, 1870–84	25.3
	Charleston, S. C.	5 years, 1880–84	34.6
	Mexico	2 years, 1876 and 1878	52.0
	Madrid	1881	37.4
	Marseilles	5 years, 1880–84	31.0
	Naples	7 years, 1878–84	32.8
	Turin	20 years, 1865–1884	27.2
	Palermo	7 years, 1878–84	24.5
	Budapest	10 years, 1870–79	42.7
	Moscow	2 years, 1879 and 1880	39.9
	Riga	13 years, 1870–1882	28.8
	St. Petersburg	Recent years	40.0
	Pekin	Recent years	50.0
	Cairo	Recent years	37.0
	Average		35.8

	City.	Period Included.	Rate per 1000 Living.
Sewered.	London	20 years, 1865–84	22.7
	Twenty large English cities	10 years, 1869–78	24.9
	Glasgow	10 years, 1871–80	28.1
	Edinburgh	Average of 5 years, 1874, '78, '79, '83, '84	20.9
	Brussels	10 years, 1875–84	26.3
	Berlin	15 years, 1870–84	30 5
	Breslau	10 years, 1875–84	31.7
	Hamburg	10 years, 1875–84	25.0
	Dantzic	10 years, 1875–84	28.9
	Frankfort	20 years, 1865–84	20.4
	Munich	10 years, 1875–84	33.7
	New York	20 years, 1865–84	28.0
	Brooklyn	15 years, 1870–84	24.1
	Boston	20 years, 1865–84	23.9
	Chicago	20 years, 1865–84	21.5
	Average		26.0

Boccaccio, in the introduction to his "Il Decamerone," says that in Florence alone upwards of 100,000 persons perished by the Black Death between March and July, 1348. Italy, says Rochard, was almost depopulated. Geneva lost 40,000 inhabitants, Naples 60,000, Venice 70,000. In the brief space of four years all Europe was scourged, and it is estimated that not less than 40,000,000 perished. In 1665, in London, no less than 100,000 died of this disease. Marseilles suffered a terrible epidemic as late as 1720, Moscow in 1771. It appeared also in Malta in 1813, and in the Balearics in 1819. This disease is still present in Western Asia, and it even invaded certain fishing villages on the shores of the Volga as recently as 1878. See Pepys' *Diary*, vol. II.; Hecker's "The Black Death in the Fourteenth Century," chap. iv.; Rochard's "La Valeur Economique de la Vie Humaine," etc., C. R. and Mem. du Cong. Int. d'Hygiène, tome I., p. 72, etc.

An analysis was made, by the Michigan State Board of Health, of the sources whence typhoid fever was derived in that state, and the results are given in the following table.*

SOURCE OF CONTAGIUM OF TYPHOID FEVER.

Table exhibiting the reported "Source of Contagium" of cases of typhoid fever in Michigan during the year 1891.

Reported Sources.	Number of Cases.
Traced to former cases	322
Probably traced to former cases	2

* It is known that generations of contact with yellow fever has produced a partial race immunity for the negro race against that sub-tropical disease.

Query: Have the conditions of northern and civilized life, with crowding, bad water, and bad sewerage, gradually established a partial race immunity against typhoid fever among white people?

This latter disease is especially fatal to the negro.

Reported Sources.	Number of Cases.
Attributed to infected, contaminated, or surface water	1477
Attributed to drinking infected or impure milk........	8
Cases reported as coming from outside jurisdictions..	192
Attributed to defective sewerage, or drainage........	44
" " filthy or unsanitary conditions..........	117
" " going in swimming, and going in water	2
" " stagnant water........	9
" " malaria	8
" " overwork........................	3
" " *la grippe*.......................	3
" " taking cold...	2
Cases reported as "sporadic"....................	9
" " to have arisen *de novo* (1 "spontaneous," and 6 "local")........................	18
Cases the sources of contagium of which were reported as unknown........................	560
Cases the sources of contagium of which were not reported, or the statements were too indefinite for classification	1894
Total..................................	4670

So long as a water is bright, and pleasant to the taste, it is next to impossible to persuade the average well-owner that it is unfit for use, and a suggestion to pour carbolic acid or kerosene into the neighboring privy vault may be rejected as "liable to spoil the well." After all sources of possible danger have been examined, it must be admitted that outlying isolated cases of typhoid fever are often difficult to explain; but it should not be forgotten that the disease does not manifest itself until a considerable time after infection, the incubation period being usually about fourteen days, and therefore the possibility of its having been imported must be always borne in mind.

"After the reception of the infection, there is, in all

communicable diseases, an interval during which the patient remains in apparent health, or perceives at the most some languor. This period lasts from one to five days in the case of cholera. For typhoid fever its duration varies from nine days to three weeks. The latter disease begins so gradually that the patient generally does not come under the observation of a physician until he has had the fever for several days. If water infected by typhoid fever dejecta were to be drunk by a considerable number of persons August first, the first case would appear about the ninth or tenth, and fresh cases would continue to appear until the twenty-third. There would be more on the fourteenth or fifteenth than at any other time. The deaths would nearly all occur the next month—September. These laws of development are of great aid in discovering the cause of brief epidemics, by indicating the period in which it must have been common to all the persons attacked." (E. J. Matson.)

An argument always advanced against the proposition that a typhoid epidemic in a town is to be accounted for by the use of a contaminated water-supply, is that only a few of the inhabitants are attacked, while all use the water. Why should the majority escape? For full discussion of the wide subject of "immunity," thus introduced, the reader must be referred to the extensive monographs written thereon; but let it be here said that recent investigations tend to support the view, advanced by Sternberg in 1881, that immunity depends upon an inherited or acquired tolerance to the toxic products of pathogenic bacteria.

He shows how putrefactive bacteria, introduced into drawn blood, maintained artificially at body temperature, will quickly multiply and produce decomposition, while the same "dose" of bacteria injected into the circulation of a living animal will rapidly disappear and leave no trace.

So likewise, in many cases, with pathogenic organisms.

The invading bacterium is seized upon by the guardian leucocytes of the blood, and destroyed by a process of assimilation, provided "the captors are not paralyzed by some potent poison evolved by their prisoner, or overwhelmed by its superior vigor and rapid multiplication."

A single disease germ may prove fatal, as has been shown by Cheyne, who experimented upon guinea-pigs with anthrax; but, if any considerable degree of vital resistance be present, the "bacterial dose" may have to be very greatly enlarged to produce observable effects. Thus, the above investigator found that "for rabbits the fatal dose of the microbe of fowl cholera is 300,000 or more, that from 10,000 to 300,000 cause a local abscess, and that less than 10,000 produce no appreciable effect." He found 225,000,000 of the *Proteus vulgaris* fatal to rabbits, but that less than 9,000,000 gave an entirely negative result.

Another interesting point that arises in this connection is the wide difference between the intensity of the attacks induced by a "virulent" and an "attenuated virus." It is well known that, if the conditions attending the cultivation of a pathogenic microbe be unfavorable to its ready growth, if they be just short of the death point, if the germ be obliged to struggle for existence through successive generations, the result is an organism of less vigorous constitution, and one capable of producing only a fraction of the amount of "toxin" elaborated by its sturdy progenitor.

Inoculation with such "attenuated virus" might be fatal to the very susceptible, but a larger number of the resistant portion of the community would escape, and the great majority of all cases occurring would be designated as "mild."

We constantly hear of the great preponderance of "mild" cases reported during the prevalence of city epidemics of typhoid fever, and our thoughts naturally turn to attenuation of virulence caused by unfavorable surround-

ings (e.g., the conditions of water-carriage) as an explanation of the observed fact.*

The first, or at least one of the first, to call attention to the relation between water and typhoid fever was Dr. Michel, of Chaumont, France.† In 1855 he observed that typhoid, which was epidemic in the above place, varied in number of cases and in intensity inversely as the quantity of water in the public wells.

Pettenkoffer, of Munich, about the same time, undertook extended observations upon variations in the height of ground-water, and, a little later, relationship was shown between these variations and the occurrence of typhoid fever.

Those who hold with Pettenkoffer claim that the elements of the disease readily multiply in the soil, and are driven therefrom, along with the ground-air, upon the rising of the water level at the time of the autumnal rains.‡

Latham, in speaking upon this point, says:

"No great variation in the vertical rise and fall of sub-soil water is the healthier condition. The ground always contains air, and, as the ground-water sinks, air is drawn in to supply its place. After long dry weather the air of the soil is thus laden with products of decomposition. A rain now occurring, the ground-air is displaced, and since said rain is liable to seal the surface, the tendency of the air is to escape laterally, i.e., into cellars. Dry summers invariably mark unhealthy years. Typhoid fever occurs after the autumn rains.

"All the great epidemics of typhoid have occurred in years when the ground-water was especially low, and after a slight rise in the same."

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* Note also Miquel's theory of auto-intoxication of water. See Chapter XI.

† "Influence de l'eau potable sur la santé publique." Paris, 1889.

‡ Typhoid fever is essentially an autumn disease, as may be seen from the

Pettenkoffer's "ground-air theory" is not gaining the majority of supporters, a more reasonable view being that, as the water surface lowers in a well, the base of the cone of drainage, whose apex is at that surface, is extended, and consequently, more widely situated points of pollution are embraced with its influence.

Perhaps the most exhaustive examination of the relation of the height of ground-water to the prevalence of typhoid

following statistics. One authority ventures to suggest that bacteria, like other plants, have their own particular seasons for growth.

DEATHS FROM TYPHOID AND TYPHO-MALARIAL FEVERS IN CONNECTICUT FOR EIGHT YEARS, ARRANGED BY MONTHS.

(From the State Board of Health.)

	1883	1884	1885	1886	1887	1888	1889	1890	Average 1883-1890
January	20	31	20	13	14	11	24	26	19.9
February	15	14	15	9	10	11	13	18	13.1
March	20	15	19	18	13	16	19	11	16.4
April	22	20	17	15	12	8	13	17	15.5
May	24	16	8	23	12	17	16	15	16.4
June	13	15	13	11	8	9	13	13	11.9
July	23	19	30	16	13	17	29	20	20.9
August	67	46	37	51	30	36	47	35	43.6
September	61	51	49	43	34	58	49	49	49.2
October	78	72	39	39	28	75	49	60	55.0
November	45	55	31	35	27	31	30	41	36.9
December	48	25	17	25	24	25	12	23	24.9
Total	436	379	295	298	225	314	314	328	323.7

The prevalence of typhoid during the autumn, as shown by the above table, is also markedly illustrated by the returns of the Ohio State Board of Health for the year 1892.

The number of deaths from typhoid fever, as reported by months, was as follows:

January	38	July	52
February	27	August	71
March	32	September	105
April	19	October	78
May	27	November (1891)	86
June	36	December (1891)	40

The total number of deaths in the State from typhoid was 611, which is a rate of 4.8 per 10,000 inhabitants.

that has been made in America, is to be found in the work of the State Board of Health of Michigan.

Observations have been made by that board during a period of many years, and the results, graphically shown herewith, indicate in a very marked manner that increase of typhoid and lowness of water in wells move in practically the same curve of variation.

So convinced were the Michigan authorities of the truth of this proposition, that they issued, during the autumn of 1894, a circular of warning, which is here quoted in part:

"*Beware! Unusual Danger now from Typhoid Fever, because of Drought.*

" The water in the representative well, near the centre of the State, last September was three inches more than the average of previous years; this year it is four inches less than the average.

" For the second week in September, typhoid fever is reported from thirteen places more this year than last year, etc., etc."

The Michigan statistics go, further on, to show that in October, 1894, the water in the standard well stood eleven inches lower than in October, 1893, and seven inches lower than the October average for the eight years, 1886-1893.

For September, 1894, typhoid fever was reported from 121 places in the state, an increase of forty-six places over the report for September, 1893.

For October, 1894, typhoid was present at 165 places, as against 109 for the same month of 1893.

For October, 1894, the prevalence of the disease was forty-four per cent above the October average for the eight years, 1886-1893.

During the three months of September, October, and November, 1894, the ground-water of Michigan grew constantly lower. It is difficult to see just how these data

could be made to fit the "ground-air" theory of Pettenkoffer or Latham as a cause of typhoid fever; for such theory calls for sudden rise in ground-water level.

The precipitation data for Michigan are given in the table on page 82.

It has been the continued experience in Michigan that typhoid is coincident with low ground-water, as is illustrated graphically on page 83, and is not dependent upon sudden rise in the same.

An interesting exception to this rule has been noted, occurring during the season of heavy frost, when surface pollution is prevented from reaching the subsoil.

The second table on page 82 was furnished me by Dr. Henry B. Baker, secretary of the Michigan State Board of Health, to whom I am also indebted for much other information.

We do not possess in New York such complete records as to the condition of the ground-water as they have in Michigan; but the rainfall, upon which ground-water depends, is on record, and the reports show that more than the average amount of rain fell in New York during the autumn of 1894, following, as it did, an exceedingly dry summer.

If typhoid fever bear relation to sudden rise in level of ground-water, as has been held, rather than to the prolonged low state of such level, as is taught in Michigan, then surely the autumn of 1894 was a very favorable time for a marked outbreak of the disease in the state of New York, but no such condition is reported by the sanitary authorities.

Just how the year of 1894 compared, in the matters of typhoid and rainfall, with 1893 and 1891, may be seen from the chart on page 84.

The above years were chosen for comparison because the summer of 1893 was very wet, and because the entire year of 1891 was especially noted for prevalence of typhoid fever.

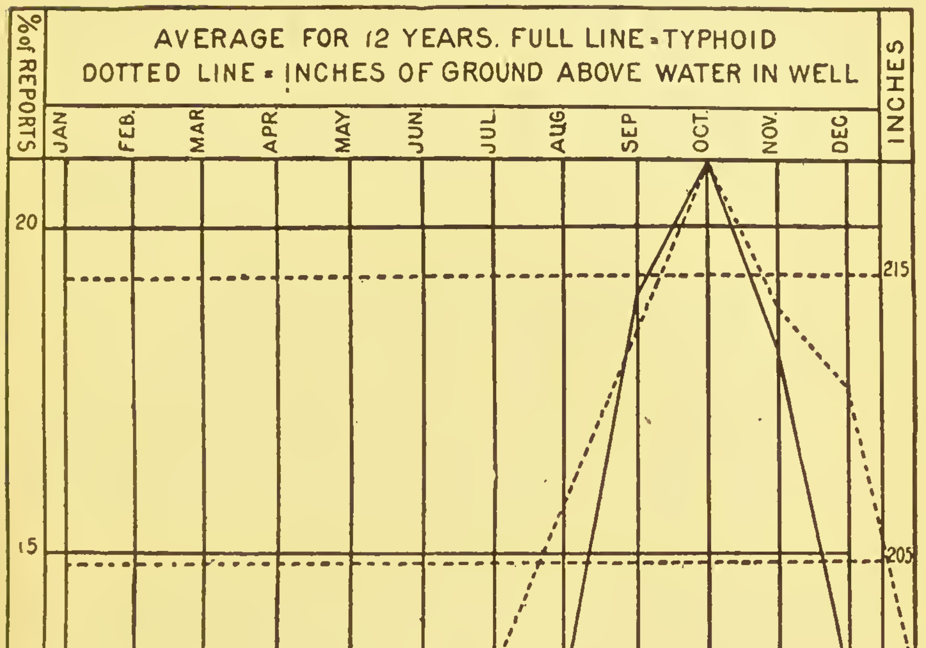
PRECIPITATION DATA FOR MICHIGAN.

	1893	1894	Normal
January	2.55	1.88	2.18
February	2.65	1.81	2.67
March	2.39	2.16	2.32
April	4.43	2.28	2.44
May	2.79	5.79	3.52
June	3.26	2.82	3.91
July	2.74	1.40	3.09
August	1.19	0.49	3.04
September	2.34	3.42	3.00
October	3.67	2.86	3.05
November	2.90	1.76	3.02
December	3.64	1.33	2.51

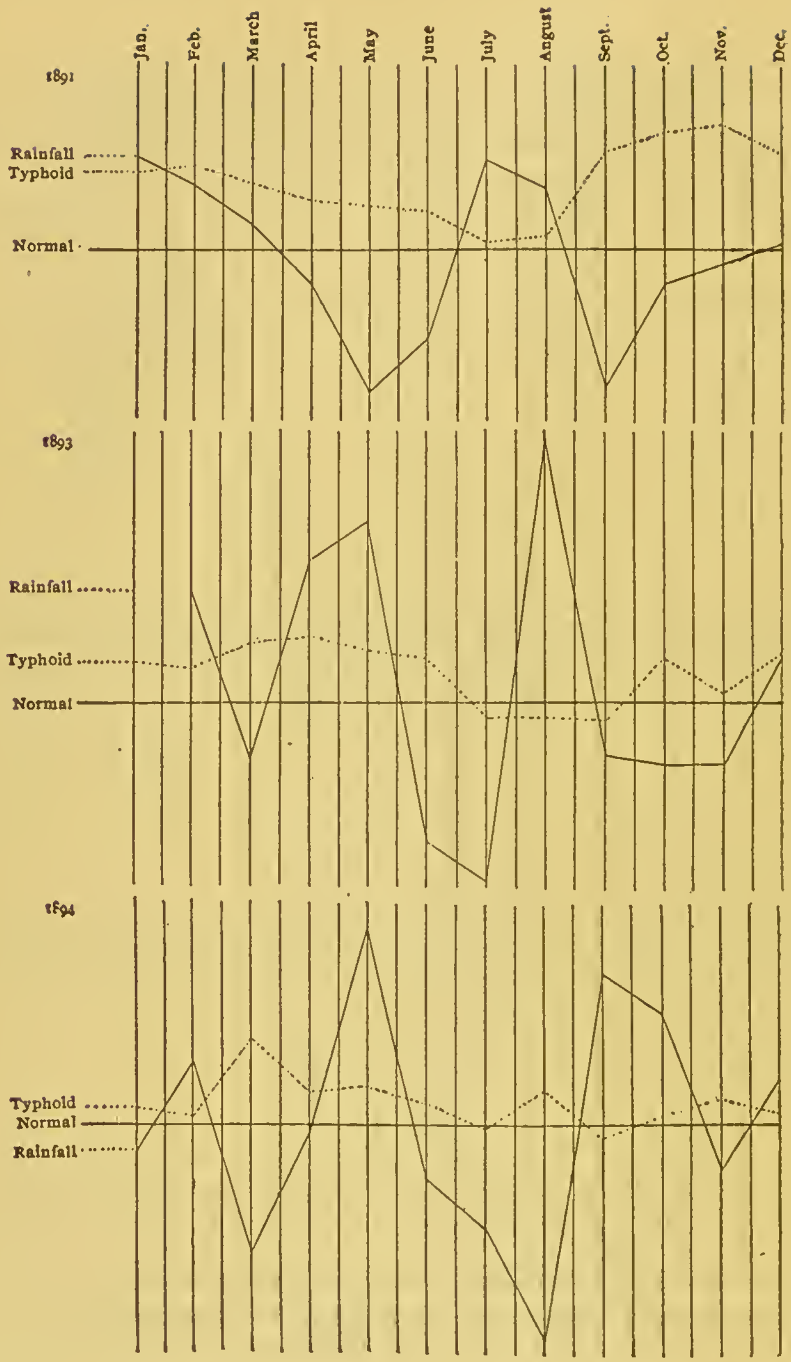
AVERAGE TOTAL ANNUAL RAINFALL

At Stations in Michigan the same for Lansing, the Inches of Earth above the Ground Water at Lansing, the Inches of Water in an Undisturbed Well at Lansing, and the Reported Sickness from Typhoid Fever in Michigan, as Indicated by the Per Cent of all the Weekly Card-reports which Stated the Presence of Typhoid Fever during the Seven Years and Each of the Seven Years, 1885–91.

Year, and Period of Years.	Average Total Annual Rainfall at Stations in Michigan, in Inches.	Total Annual Rainfall at Lansing, in Inches.	Inches of Earth above the Ground Water at Lansing.	Inches of Water in an Unused Well at Lansing.	Ground Water Higher (+) or Lower (−) than the Seven Years' Average in Inches.	Average Per Cent of all Weekly Card-reports Stating the Presence of Typhoid Fever.	More (+) or Less (−) Sickness from Typhoid Fever than the Seven Years' Average.
Av. 7 years, 1885–91	31.06	29.45	293	31	=	9	=
1885	35.82	34.51	284	40	+ 9	8	− 1
1886	32.16	29.52	281	42	+ 11	8	− 1
1887	29.82	30.08	290	34	+ 3	10	+ 1
1888	29.55	25.76	294	29	− 2	10	+ 1
1889	28.18	23.28	304	19	− 12	10	+ 1
1890	30.20	33.96	300	28	− 3	8	− 1
1891	31.66	29.05	301	23	− 8	11	+ 2



COINCIDENCE OF PREVALENCE OF TYPHOID FEVER AND LOWNESS OF WATER IN WELLS. (STATE OF MICHIGAN.)



RAINFALL AND TYPHOID FEVER. VARIATIONS FROM NORMAL. (STATE OF NEW YORK.)

These curves are very irregular, and suggest in places relation between low rainfall and prevalence of the disease; but the remarkable concordance exhibited in the Michigan chart is here sought in vain.

New York does not stand alone in its failure to accord with the Michigan rule, as is seen from the following Connecticut statistics:

	1894.		1893.		Normal.	
	Rainfall in Inches.	Deaths Typhoid.	Rainfall in Inches.	Deaths Typhoid.	Rainfall in Inches.	Deaths Typhoid.
July	2.40	15	1.89	18	4.99	14.8
August	1.70	38	4.86	14	5.17	32.8
September.....	4 63	38	2.24	37	3.76	41.4
October.........	6.11	32	4.75	49	3.90	42.6
November.....	4.23	37	2.56	35	3.90	40.2

As elsewhere, so in Connecticut, the summer of 1894 was very dry, and very heavy rains fell in the autumn, yet the autumn death-rate was below the normal. If any weight is to be attached to the *sudden rise* in ground-water, surely here was an opportunity for its exhibition; but the rise in water level was followed by no increase in typhoid.

Minnesota was also an apparent exception to the Michigan rule, as we see from the following:

	1894.		Normal.	
	Rainfall in Inches.	Deaths Typhoid.	Rainfall in Inches.	Deaths Typhoid.
August................	1.22	39	2.80	43
September............	2.04	42	2.04	67
October..............	3.37	47	1.55	87
November............	0.54	30	0.69	62

This state presents a refutation of the "ground-air" theory, for there was certainly a "sudden rise" in level of the ground-water, without corresponding increase of ty-

phoid; but there was no real exception here to the "Michigan rule," for it will be remembered that the said rule calls for marked lowness of ground-water, and we notice that the autumn rainfall was above the normal in this state.

Among the other states heard from, the majority unquestionably fall under the Michigan rule. Definite information regarding mortuary statistics was, in the cases of many states, impossible to secure, and only such expressions as "considerable typhoid," "largely increased typhoid," were obtainable. No statistics whatever are kept in certain states, and from them no results could be recorded.

The health department of Iowa writes, under date of December 17, 1894:

"There is greatly increased typhoid fever in this State. Scarcely a town or township is exempt."

The Iowa rainfall was:

	1894.	Normal.
August	1.58	3.60
September	3.57	3.70
October	2.67	2.85

Here again is noticed the probable low condition of ground-water, and the application of the Michigan rule.

The Board of Health of Ohio writes: "We have noticed a very decided increase of typhoid fever in our State during the past autumn. It has also been noticable that the increase has been almost wholly in our small villages, where wells are used for water-supply."

The Ohio rainfall was:

	1894.	Normal.
August	1.67	3.04
September	3.31	2.94
October	2.01	2.57
November	2.17	2.99

This was also an instance of prolonged low water, with results following the rule.

In Pennsylvania, the records show large amount of typhoid present during the autumn of 1894, with rainfall as follows:

	1894.	Normal.
August	1.84	4.90
September	6.30	3.72
October	4.26	3.48
November	2.50	3.33

A word is necessary here regarding the great precipitation for September. It will be remembered that, on the eighth of that month, an exceedingly violent but short storm swept over the eastern coast of the United States, with very heavy rainfall.

A great portion of this rain found its way directly to the streams and water-ways, and the ground-water received but little reinforcement.

In Maryland "there has been a decided increase in the number of typhoid fever cases during the past six months (i.e., June to December, 1894) in all parts of the State. The rate of mortality has been low."

The rainfall was:

	1894.	Normal.
August	1.55	4.76
September	2 45	3.87
October	3.17	3.76
November	3.65	2.78

Low condition of ground-water is here very apparent, and the State falls under the rule.

In Wisconsin "there is thought to have been a slight increase of typhoid in the State during the past autumn (1894), but not very marked."

The Wisconsin rainfall was:

	1894.	1893.
August	0.78	2.03
September....	3.58	2.32
October....................	3.04	2.49
November........................	1.93	1.33

Comparison with the normal for this State is not possible from the data in the writer's possession. It will be noticed, however, that the autumn was probably wet, and the typhoid was practically normal.

The author does not possess the normal values for Massachusetts, but a comparison of 1894 with the previous year stands as follows:

	1894.		1893.	
	Typhoid.	Rain.	Typhoid.	Rain.
August...............	27	1.75	40	5.22
September....	83	3.46	60	2.38
October..............	60	4.96	116	4.01
November............	58	3.36	104	2.17

Evidently, Massachusetts is not to be rated as in accord with the Michigan rule.

In Indiana, so far as the Board of Health has been advised, "there has been about the usual amount of typhoid fever, following dry weather, more than there is after a season of plentiful rainfall."

The Western States, so far as heard from, are thus seen to follow, as a class, what has been styled the "Michigan rule," with the apparent exception of Minnesota; but it has been shown that this is really no exception at all in view of the more than normal rainfall. Now, what reasonable explanation can be given for the failure of New York, Connecticut, and Massachusetts to accord with the rule?

While not wishing to dogmatize upon manifestly scanty data, the suggestion is offered that, so far as these three States are concerned, larger shares of their populations derive

their drinking-water from more or less carefully selected sources of public supply, and are conseqently less exposed to the danger arising from the local contamination of private wells.

Whether the exhaustive study of facts does, or does not, support the view that the relation of typhoid fever and rainfall, so far as ground-water is concerned, deals with the question of low ground-water, rather than with fluctuations in its vertical height, it admits of ready illustration that marked relationship certainly exists between this disease and the sudden influx of storm waters, flooding the polluted foreshores of smaller rivers. We have seen such a case in the epidemic of typhoid, in the valley of the Tees, page 28.

However much the statistics referring to Asiatic cholera, and especially to typhoid fever, may be considered as especial indicators of the purity of a town's water-supply, it must not be supposed that the general death-rate is unworthy of careful study as well.

It is widely known that the present potable supply for Paris is vastly superior to the water from the Seine, which, until recently, was all that the inhabitants had for domestic use. The following figures, giving the total death-rate for a group of five years before the introduction of the purer water and for a similar period after the Seine had been abandoned for drinking purposes, well illustrate the benefit of the change.

	Total Deaths.	Rate per Thousand.	Average.
1860	41,261	24.32	24.57
1861	43,664	25.74	
1862	42,185	24.87	
1863	42,582	23.33	
1864	44,913	24.60	

1888	53,303	21.99	22.89
1889	56,059	23.12	
1890	56,660	23.37	
1891	54,443	22.45	
1892	57,137	23.53	

These averages show a saving of 1.68 per thousand, or, based on the last stated population of 2,424,705, they represent the preservation of 4072 lives annually in the city of Paris.

Still more striking are the statistics furnished by San Remo, a town of 18,000 inhabitants, situated upon the Italian Riviera. The present superb water-supply (introduced December, 1883) comes from the mountains, and is one of the best in Europe, while the former one was derived from shallow domestic wells sunk into a filthy city soil. The following table for total death-rate is interesting:

	Total Deaths.	Rate per Thousand.	Average.
1879	362	22.37	22.61
1880	368	22.74	
1881	320	19.75	
1882	347	21.30	
1883	441	26.91	
1884	312	18.91	19.65
1885	409	24.65	
1886	334	20.10	
1887	331	19.81	
1888	270	15.90	
1889	353	20.37	
1890	307	17.34	
1891	317	17.92	
1892	352	19.83	

It will be observed from the above averages that the total death-rate has been lowered a trifle over 13 per cent by the introduction of pure water. Still more striking is a

statement made to the author by Dr. Martemuci, the leading local physician. He said: "Where I now have one typhoid case, I had forty before the change in the water-supply."

The following is extracted from the report of the New Jersey State Board of Health for 1893.

To show a part, at least, of the effect of polluted water-supplies in the large cities of the state, the populations of five of the larger cities from 1880 to 1890, and the record of deaths from enteric diseases as recorded by the report of the Bureau of Vital Statistics, are given in the following table. Enteric diseases are ordinarily the most competent to show the effect of specific pollution in potable water.

	Trenton.	Camden.	Paterson.	Jersey City.	Newark.
Population, 1880..........	29,910	41,659	51,031	120,722	136,508
Population, 1890..........	58,488	58,274	78,358	163,987	181,518
Average pop. for decade..	44,199	49,966	64,699	142,354	159,013
Total deaths from enteric diseases for 11 years....	163	541	302	1,121	1,061
Average number deaths, etc., for each year......	14.8	49.1	27.4	102	96.3
Death-rate per 10,000 from ent.ric diseases.........	3.3	9.1	4.2	7.2	6.0

From this table it will be seen that Trenton, taking its water-supply from the Delaware above the city—almost entirely unpolluted by sewage—has the lowest death-rate; it is closely followed by Paterson, which takes its water from the Passaic above the falls, and before serious pollution occurs; while Newark and Jersey City, both supplied from the lower Passaic, largely polluted by sewage, and Camden, supplied from the lower Delaware at a point affected by the sewage of Camden, Philadelphia, and the entire population as far up the river as Trenton, all have abnormally high death-rates. Had Newark's rate for the decade been no greater than Trenton's, a saving from enteric fever alone of 429 lives would have been effected among its people;

and if Jersey City had the same rate, 553 persons would have been saved. Could figures be more convincing? It should be understood that these are not statistics collected in support of any preconceived theory, but are the official returns of the State Health Department, and, therefore, should be given the weight of unprejudiced authority.

As cities increase in size there are introduced into the total death-rate disturbing factors that must be considered in comprehensive study. Thus, the influence of simple crowding is well illustrated by the following statistics for various London districts: *

		Mean Death-rate, 1885-91.
Districts with a density of	under 40 persons per acre	15.27
Do.	from 40 to 80	19.04
Do.	from 80 to 120............	19.24
Do.	from 120 to 160..........	22.60
Do.	over 160.................	23.88
County of London, with a density of over 57	....	19.90

Finally, in view of the intensely practical spirit of the age, let us consider the question,

Does pure water pay? †

To abandon an existing water-supply system or to purify the polluted water that it furnishes, always involves the

* *Engineering News*, Dec. 28, 1893.

† A suit for damages for the death of a man from typhoid fever, alleged to have been caused by drinking impure water, has been brought by a widow in a Western city.

"We cannot expect to find the effect of impure water always sudden and violent. The results of continued imbibition of polluted water are indeed often gradual and may elude ordinary observation, yet be not the less real and appreciable by close inquiry. In fact it is only when striking and violent effects are produced that public attention is arrested; the minor and more insidious, but not less certain evils, are borne with the indifference and apathy of custom." (Fox, "Water, Air, and Food.")

outlay of much money, and the city taxpayer has the right to inquire whether or not the benefit derived is a fair equivalent for the cash expended. Impure water affects the yearly death-rate, as a whole, much less than that section of it which deals with diseases recognized as "water-borne," prominent among which is typhoid fever. No better measure can be selected of the wholesomeness of a city supply than that furnished by a list of the annual cases of this serious disease.

Typhoid fever is doubtless, to a very large extent, a preventable disease, but the means of prevention, in the shape of great public works, are expensive, and again the question is asked, Do these works pay? Can we afford to save the typhoid victims?

According to Rochard, the economic value of an individual "is what he has cost his family, the community, or the State for his living, development, and education. It is the loan which the individual has made from the social capital in order to reach the age when he can restore it by his labor."

The statement of this value, in form of money, is a difficult matter, which has been variously settled by sundry investigators. Chadwick considers an English laborer equivalent to a permanent deposit of £200 (say $980). Farr gives £159 (say $780) as the average value of each human life in England. A French soldier is rated as worth 6000 francs (say $1200).

In view of the fact that typhoid fever selects by far the greatest number of its victims from among those in the very prime of life, to the relative exclusion of the very young and the very old, it will be reasonable to follow the figure fixed upon by E. F. Smith, and place the loss caused the community by a death from typhoid at $2000. This will be noticed to be less than half the figure so frequently referred to in the courts of this State for the value of a human life

For the sake of illustration, let us consider the tax levied annually by typhoid fever upon a city of one hundred thousand inhabitants; for instance, Albany, N. Y.

From statistics given in the last five annual reports of the State Board of Health, the deaths due to typhoid fever in Albany average seventy-five for the year.

Rating the money value of each life at the figure given above, this death-rate would mean an annual pecuniary loss to the city of $150,000.

Funeral expenses are variously estimated at from $20 to $30. Should we accept the intermediate value of $25, this item would cause $1875 dollars to be added to the above sum, thus raising the total direct loss through death to $151,875.

But typhoid fever does not always kill. Its mortality rate is commonly quoted at about ten per cent. For the present purpose, should we assume nine recoveries for each death from the disease, and place 43 days as the period of convalescence (the average of 500 cases at the Pennsylvania Hospital), we should have a term of 29,025 days as representing the time lost, per year, by the 675 persons who have the fever and recover. Thus an annual loss of over 79 years has to be borne by the city's capital of productive labor.

This great amount of enforced idleness, when translated into money value, should very properly be added to the death loss above estimated.

Fixing the rate of wages at $1 per individual per day—a very low figure, considering that the bulk of typhoid patients are in the very prime of life—there is a loss of $43 of wages for each recovery, or a total yearly loss for the city from this item of $29,025. The cost of nursing and doctors' bills equal at least $25 per case, which is a very low estimate, thus adding the further amount of $16,875 to

the gross sum. Expressed in tabular form, this yearly tax imposed by typhoid fever upon the city of Albany is given below, and, upon a most conservative estimate, it is practically $200,000, which is $2 a year for each man, woman, and child in the city, or a yearly tax of $10 for every family of five persons.

75 deaths at $2000 each	$150,000
75 funerals at $25 each	1,875
Wages of 675 convalescents during 43 days at $1 per day	29,025
Nursing and doctors' bills for 675 convalescents at $25 each case	16,875
Total tax levied annually by typhoid fever upon the city of Albany	$197,775

It can readily be seen that public works which could eliminate a reasonable fraction of this great tax would pay for themselves in the course of a few years, even though they were originally expensive.

Finally it is right to inquire what fraction of the present typhoid loss it would be reasonable to hope to save if pure water should be served to the city in place of its present polluted supply. To answer this question recourse must be had to statistics obtained from other cities, covering periods before and after better water-systems had been introduced. Such data have been already given for a number of cities and communities, and it only remains to anticipate what will be later said of Munich, and state that improved water and sewerage have reduced the annual typhoid mortality from an average of 25.4 per 10,000 to 2.7.

Surely pure water pays in a city with such a record, and likewise it would pay in the newer but growing cities on this side of the Atlantic. Americans insist upon being

supplied with much more water *per capita* than is usually furnished in Europe, but they are singularly indifferent as to its quality. It would be a reform of great moment if they could be induced to curtail the present enormous waste of public water, such as that of Buffalo, for instance, which is stated to be 70 per cent of the entire pumpage, and to expend the money thus permitted to leak away in a vigorous effort to improve the quality of the supply. No such lowering of the typhoid death-rate as occurred at Munich, San Remo, and sundry other places could be looked for, perhaps, but a large percentage of the present rate could be cut off, and, we think, from a consideration of the above figures, that such a reduction would pay.

No weight should be attached to the argument, so often advanced by the individual householder, that he and his family "have used the water without evil result for fifty years." A single family is too small a collection of units upon which to base any estimate touching the question at issue.

Placing the typhoid death-rate for Albany, as above, at seventy-five annually, it would call for one death in a family of five persons every 261 years, a period much beyond the limits of ordinary family record.

CHAPTER III.

ARTIFICIAL PURIFICATION OF WATER.

PURE water is better than purified water; of that there can be no shadow of a doubt; but, as the former often cannot be obtained, the consumer must at times be content with the latter or go without. The art of removing suspended material from water, by some form of filtration, has been known during many ages, although it was not put in extended practice until very recent times.*

The modern methods of filtration claim to do something more, and better, than merely to strain off the grosser elements of turbidity; and so fully do the people of Europe appear to believe this claim a just one, that with them a city water-works without an attendant filter-plant is becoming almost a novelty.† The method of purifying water on the large scale, which deserves first attention on account of its early use and wide application, is commonly known as

THE ENGLISH FILTER-BED SYSTEM.

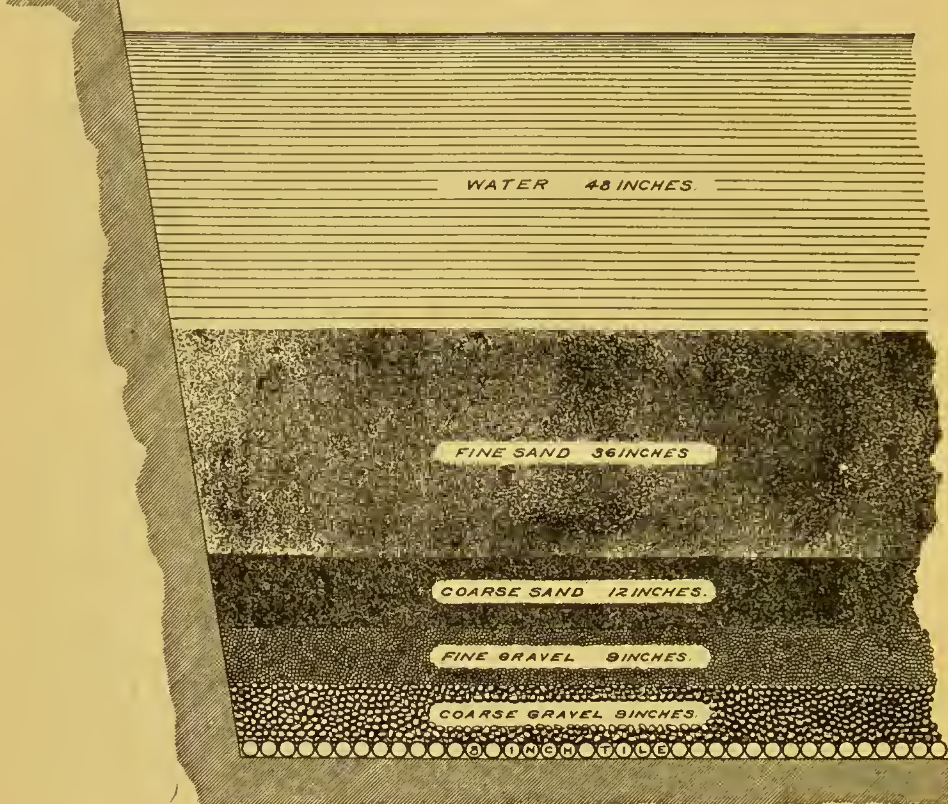
Briefly described, an English filter-bed is a tight reservoir, suitably underdrained, and containing some six feet of stratified filtering material, of progressive degrees of fine-

* The "siphoning" of liquid from one vessel to another by the capillary action of porous material, such as a strip of cloth, and the consequent separation of the liquid from suspended material, was well known to the ancients, and is frequently mentioned. (Bolton, "Ancient Methods of Filtration." *Pop. Sci. Monthly*, XVI. 495.)

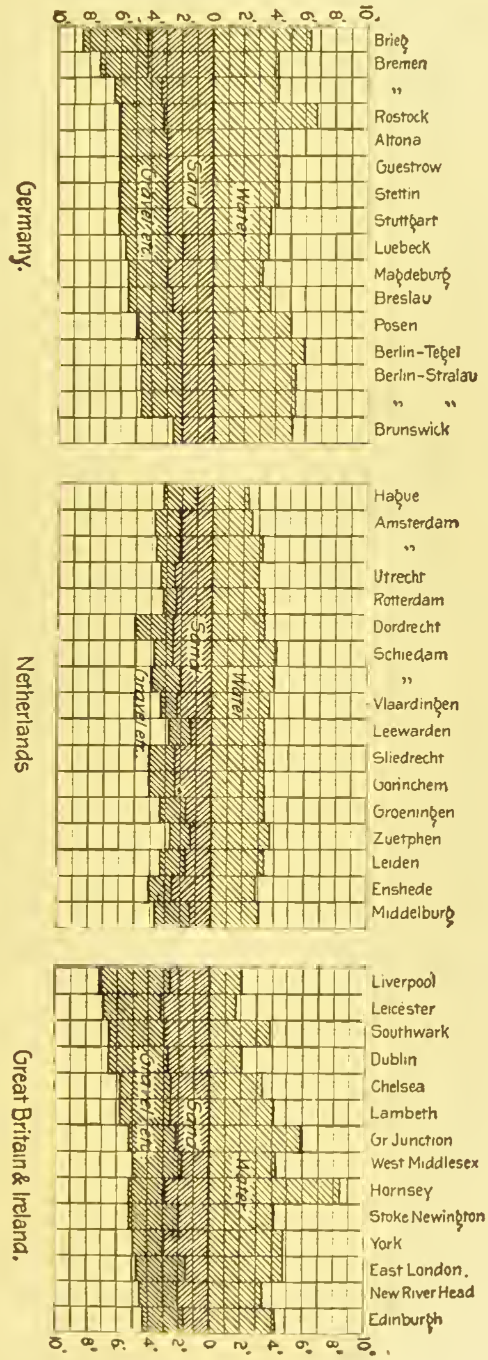
† Filtration of surface-water, before delivering the same for public consumption, is now specifically ordered by the laws of Germany, and rules are laid down for its proper accomplishment.

ness, beginning at the bottom with six inches of broken stone and ending with an upper layer of fine sand.

SECTION OF AN ENGLISH FILTER BED.
SOUTHWARK & VAUXHALL WATER CO.
LONDON.



Much diversity exists in the relative thickness of the several layers, some filters being constructed with a very thick upper layer of fine sand, while with others the finest material is put on as a comparatively thin cover. The Dutch filters are especially marked in the thinness of their beds, a feature by no means to be recommended; for, although much of the actual work of filtration is done by the upper layer of sand, yet if the thickness of the body of the bed be unduly reduced, that portion of the water which is in the act of being delivered will bear too large a ratio to that filling the interstices of the coarser layers; as a result,



COMPOSITION OF VARIOUS FILTER-BEDS.

COMPOSITION OF VARIOUS FILTER-BEDS, IN INCHES.

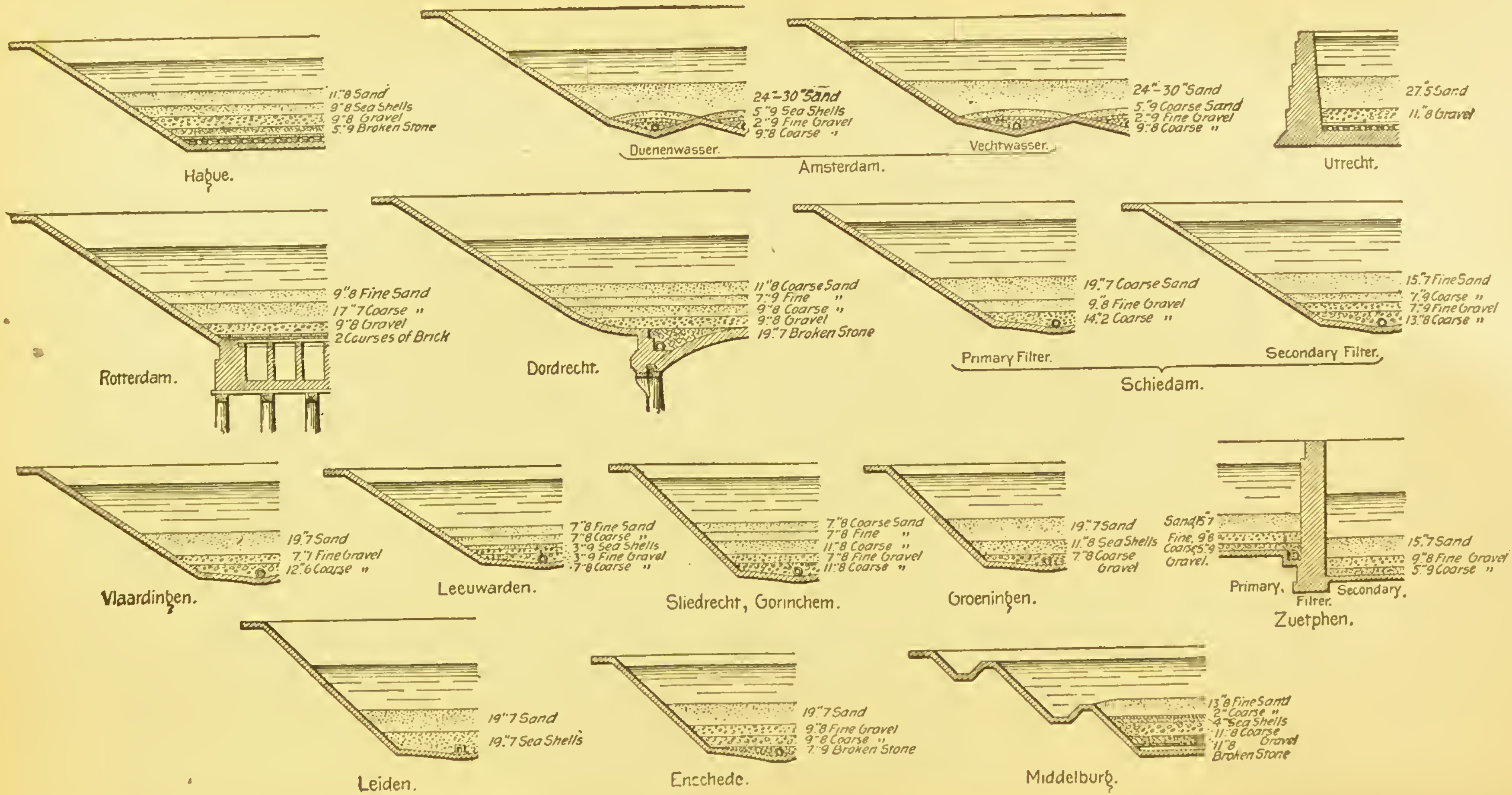
	Fine Sand.	Coarse Sand.	Fine Gravel.	Medium Gravel.	Coarse Gravel.	Small Stones.	Large Stones.	Total Depth.
Berlin	22	2	6	5	3	4	12	54
Warsaw	24	....	2	....	3	12	11	52
Zurich	32	6	4	....	6	....	....	48
Hague	12	10 (sea-shells)	....	....	10	....	6	38
Hudson, N. Y.	6	18	6	6	6	6	24	72
London: Chelsea	54	....	3 (shells)	39	....	....	....	96
London: Lambeth	36	....	12 (shells)	....	36	...	....	84
London: Southwark and Vauxhall	36	12	9	....	9	....	....	66
London: W. Middlesex	27	12	....	....	27	....	....	66
Poughkeepsie, N.Y.	24	....	....	18	....	6	24	72

currents will be established, and ruinous channel-ways be quickly worn in the uppermost stratum.

It must not be thought, however, that the extreme top layer of sand, with its cover of slime, does the entire work, so far as purification is concerned. That this is a misconception is shown by Reinsch, who has just published his observations of the Altona filters. He found the unfiltered water to contain 36,320 microbes per cubic centimetre. After passing the slime layer there yet remained 1876, but after passing the entire depth of sand there were found but 44 per cubic centimetre. Thus the lower layers have uses other than mere regulation of flow.

A decreasing, but yet positive, efficiency is noted in the lower levels of the filter-bed. (See table on page 102.)

For proper working, the thickness of the fine sand layer should be made not less than twenty-four inches, and this depth should not be permitted to fall below twelve inches, by the successive removals of layers of its upper surface for purposes of cleaning. The German law prohibits the reduction of the fine sand layer below this limit of twelve inches.



SECTIONS OF DUTCH FILTER-BEDS.

SHOWING AVERAGE ANALYSES OF SAND AT DIFFERENT DEPTHS IN FILTERS.*

Depth from Surface, in inches.	Organic Nitrogen. Parts per 1,000,000 by Weight of Dry Sand.	Bacteria per gramme.
¼	200	6,600,000
1	95	1,940,000
3	64	720,000
6	47	300,000
12	40	90,000
24	23	47,000
36	16	35,000
48	12	29,000
60	12	26,000

The engineering structures containing these various beds of filtering materials differ from one another in size, shape, and method of construction, according as the preference of the designer may dictate or the necessities of the case may demand. In London the result of long experience has been the selection of one acre as the proper superficial area of a filter-bed, and new constructions are carried on with that rule in view. Usually the inner wall-surface is nearly, or quite, vertical, but the Holland filters (see page 101) form a notable exception in this particular, having a slope, at times, of more than one to one.

An objection to an entirely vertical wall is that there is possibility of improperly filtered water passing down between it and the sand. A wall broken into steps would afford a better opportunity for a good joint being made with the sand.

The composition of the body of the side-walls is as varied as one would expect to find it among reservoirs in general; running from earth embankments with clay puddle cores, to structures of pure concrete, or even of dressed stone.

* Mass. Bd. Health, 1894.

Such as are constructed of earth are, however, carefully protected on the inside, by suitable paving, from the damaging action of ice and waves.

The new filters of the Southwark and Vauxhall Company (London) have a layer of three-inch agricultural drain-pipe, placed side by side with open joints, over the entire bottom, thus securing very perfect flow to the clear-water reservoir. (See illustration, page 98.)

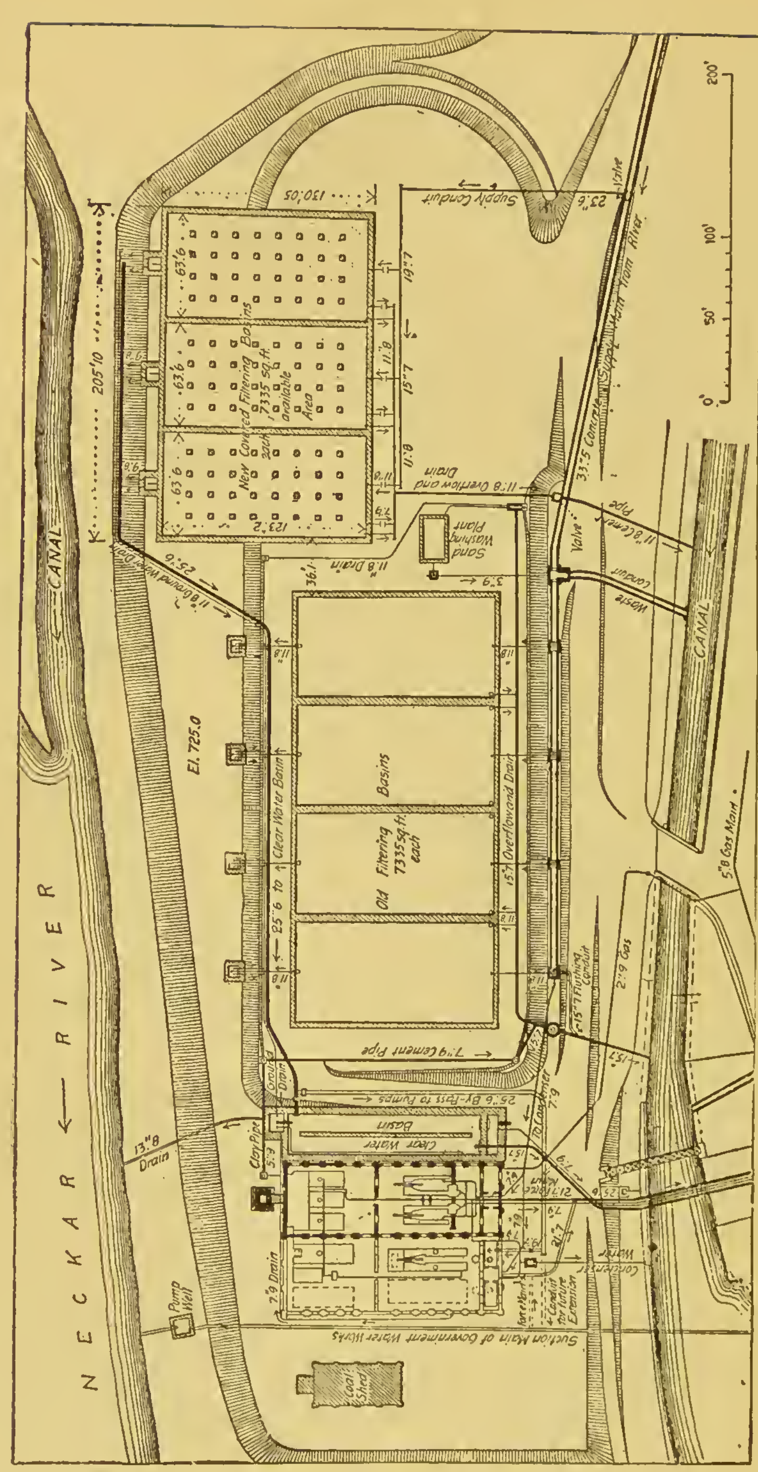
Usually these filter-plants are entirely open, but in those localities where the winters are severe, it becomes necessary to throw over them a cover, which is commonly of concrete, resting upon columns of the same material.

At Stuttgart, both the open and covered forms of filter are in constant operation, and as the latter never freeze, the relative advantages of such a form, in saving trouble from ice, may be there satisfactorily studied.

Thick ice renders it practically impossible to properly clean a filter, and the resulting imperfect purification of the filtrate is often coincident with increase in the death-rate. This was noted in Berlin in the winter of 1889, when an outbreak of typhoid fever followed the deficiency in purifying power of the open filters. That portion of the city supplied with water from the covered filters was not visited by the epidemic.

In England the climate does not demand the construction of the expensive covered filters, and, as a rule, much trouble from ice is not experienced; but even there exceedingly cold weather will at times occur, bringing with it large additions to the bill for expenses of maintenance. A notable winter in this particular was that of 1884, when seventy men were constantly employed in removing ice from the Southwark and Vauxhall beds. (See illustration on page 105.)

Mr. Allen Hazen, in his excellent work on "Filtration of Public Water-Supplies," advocates the covering of filters



OPEN AND COVERED FILTER-BEDS AT STUTTGART, GERMANY.

in all localities where the mean January temperature is below the freezing-point. His recommendation is unquestionably a sound one.

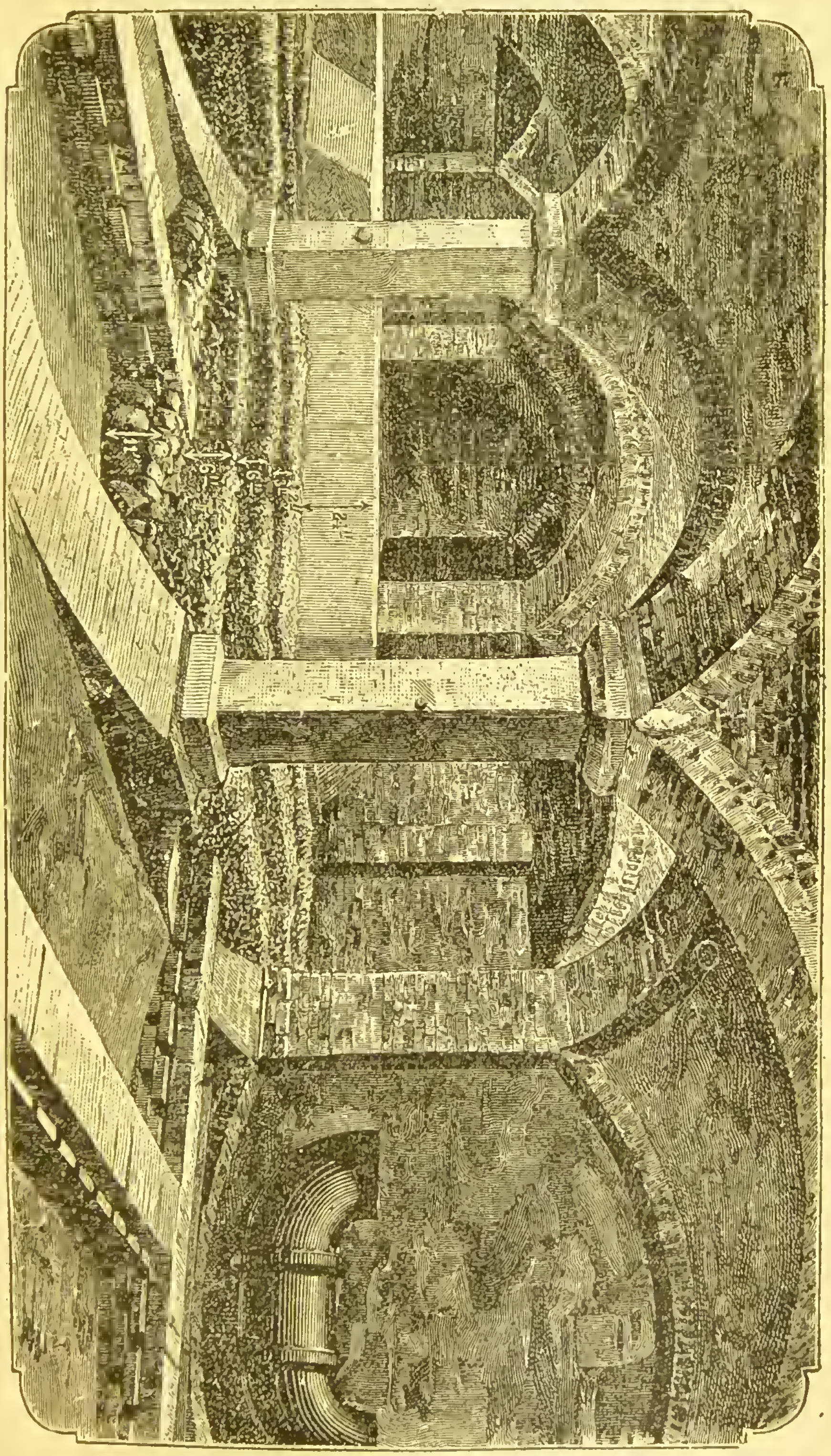
An idea of the interior appearance of a covered filter may be obtained from the cut on page 107 showing a filter belonging to the Warsaw works, in which the various layers of filtering-material are shown in section.

The engraving on page 108 is from a photograph, showing the new covered beds at Zurich, Switzerland, in process of construction.

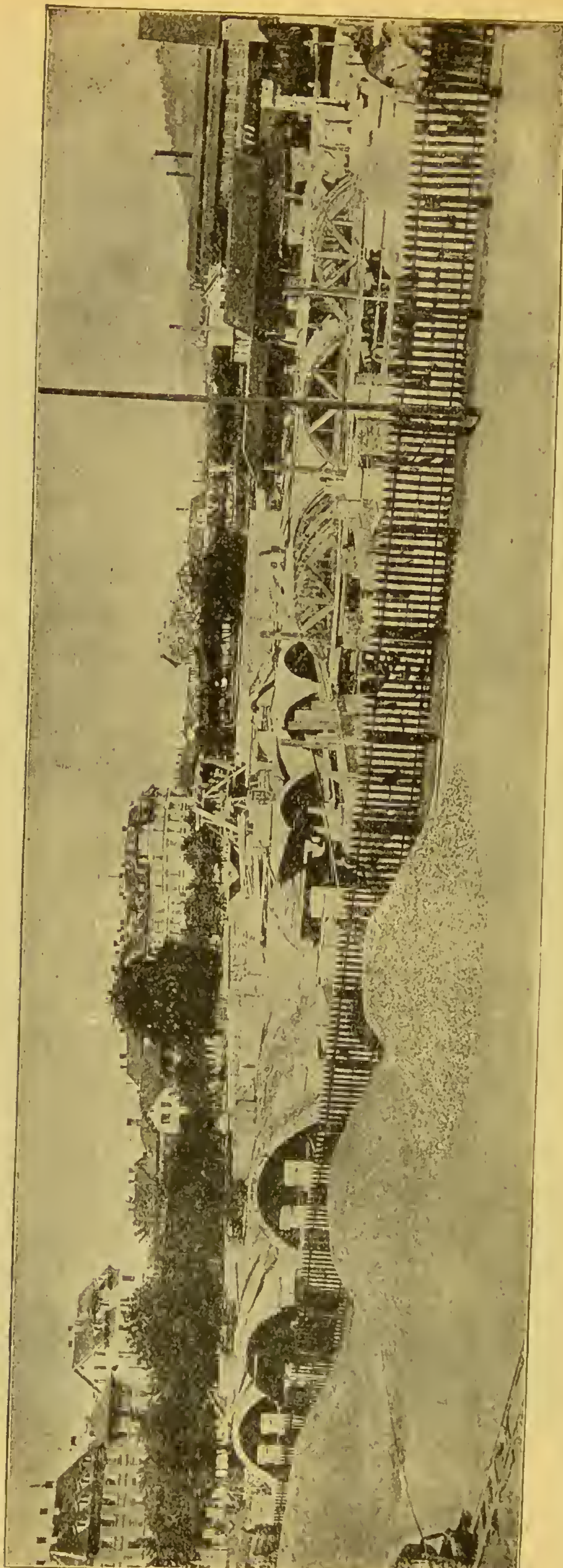
The sections illustrated on page 109, by Piefke, are of the Berlin beds.

As is well known, the great city of London buys all of its water from eight private companies, and every gallon delivered for use is carefully filtered by the said companies, with the exception of what is derived from deep wells in the chalk. Certain statistics relating to these great plants are here given:

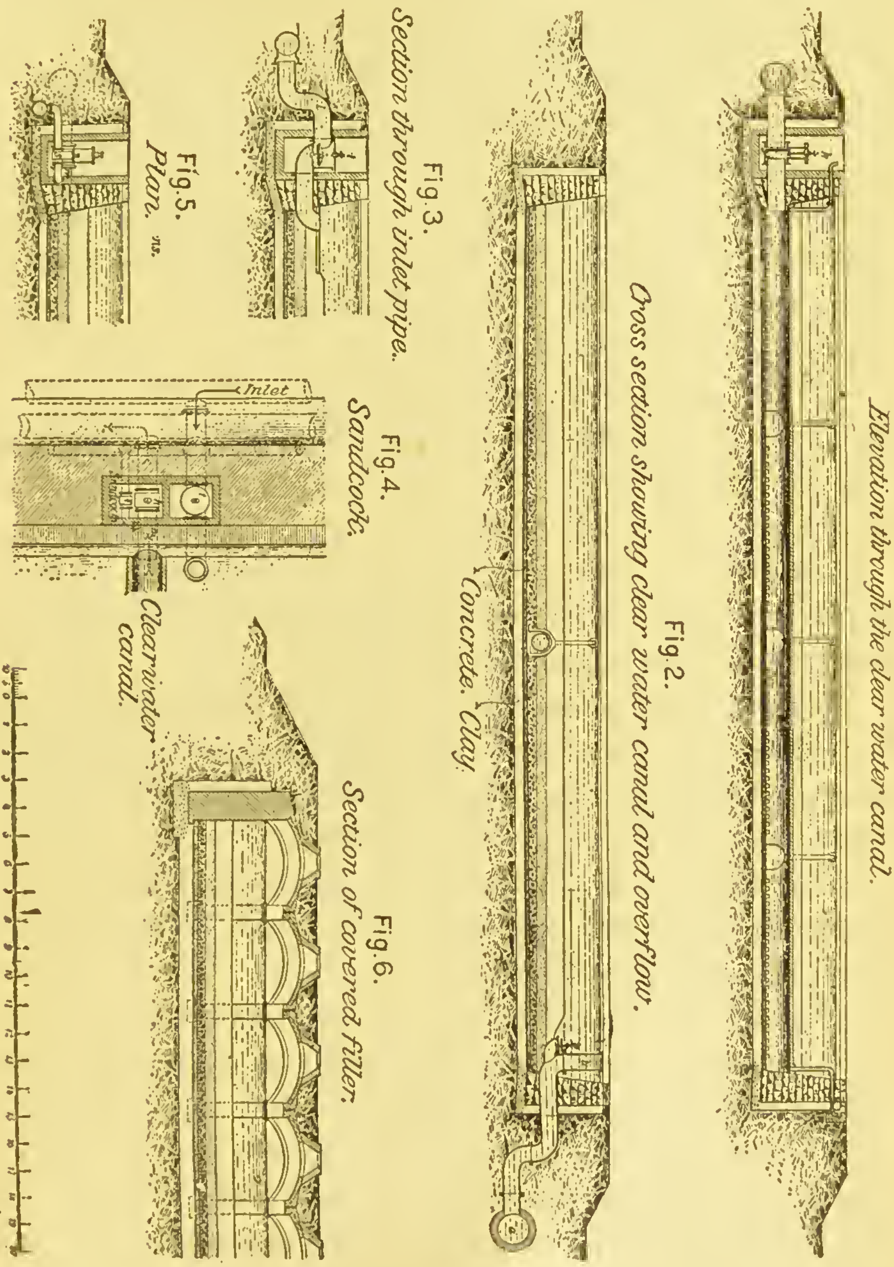
Name of Company.	Source of Supply.	Daily Supply in U. S. Gallons.	Number of Filter-beds.	Total Area of Filter-beds, in Acres.	Depth of Filter-materials.
Chelsea........	Thames river	12,727,000	7	6¾	8 ft.
East London. ..	Thames river, Lee river, Chalk wells, Springs	51,495,000	31	29¾	3 ft. 6 in.
Grand Junction.	Thames river	22,391,000	15	17¾	5 ft. 6 in.
Kent..........	Deep Chalk wells	17,126,000	none	....	....
Lambeth.......	Thames river	23,509,000	10	9½	7 ft.
New River.	Chadwell spring, Lee river, Chalk wells	43,190,000	20	16½	5 ft. 7 in.
Southwark and Vauxhall.....	Thames river	34,080,000	12	14½	5 ft. 6 in.
West Middlesex.	Thames river	21,627,000	12	15	5 ft. 6 in.
Total........		226,145,000	107	109¾	....



A COVERED FILTER, WATERWORKS OF WARSAW, RUSSIA. (AFTER LINDLEY.)



COVERED FILTER-BEDS AT ZURICH, SWITZERLAND, UNDER CONSTRUCTION.



SECTIONS OF BERLIN FILTER-BEDS. (AFTER PIEFKE.)

The cost of constructing a filter-bed upon the general plan described must necessarily greatly vary, in direct ratio, with the local cost of materials, and with the difficulty of the engineering problem involved.

For some well-known plants the cost of construction is given, as follows, exclusive of the price of land:

London.—A bed one acre in filtering area costs from $24,000 to $39,000, depending on the nature of the ground. Those of the Southwark and Vauxhall plant each cost the latter sum. All these beds are uncovered.

Liverpool.—Same as London.

Zurich.—Covered beds, complete, cost 120 francs per square metre of filtering surface (about $2.25 per square foot, or $98,000 per acre). The uncovered beds, previously in use, cost two-thirds of this sum.

Hamburg.—The new filters are all open, and cost 33 marks per square metre of sand-surface (about 70 cents per square foot, or $30,500 per acre).

Berlin.—The covered filters cost $70,000 per acre, and the open ones about two-thirds that sum. Lindley gives a general estimate for the continental filters, as follows: Open, $45,000 per acre; covered, $68,000.*

Poughkeepsie, N. Y.—The two (uncovered) beds cost together (in 1870) $75,694, which is at a rate of $112,641 per acre, including price of land.

Hudson, N. Y.—The plant consists of two filter-beds, one of 9071 square feet sand-surface, built in 1874, and one of 23,017 square feet surface, built in 1888. The initial cost of the smaller bed, together with the clear-water reservoir, was $37,450. The newer and larger filter was built for $17,350—the much lower figure for the second filter being accounted for by the partial preparation of its site at the time of the earlier construction.

* See also *Engineering News*, Aug. 16, 1894.

Ilion, N. Y.—The beds are small, of 3040 square feet each in sand-area. The detailed cost is here given:

170 cu. yds. ashlar masonry	@	$10.00	$1700
332 " " rubble "	"	5.50	1826
240 " " concrete	"	5.00	1200
110 " " filtering gravel	"	1.50	165
551 " " " sand	"	1.50	827
900 " " embankment	"	.32	288
32.3 M brick, laid dry	"	8.00	258
11.8 " " " in cement	"	12.50	148
431 lin. ft. cut coping, 6 × 30 in	"	1.25	539
176 " " " " 4 × 12 in	"	.35	61
247 sq. ft. 6-in. Hudson R. bluestone flagging	"	.40	99
Total			$7111

This is at a rate per acre of $101,900.

These figures do not include sedimentation basins, which are essential in all cases where the water to be filtered is materially turbid. These basins need not be of great size. Storage sufficient to equal the twenty-four hours' supply is quite enough, for in that time the great bulk of suspended material will settle, and the balance can be economically removed by the filter. Where no settlement is permitted before running a turbid water upon the filter, an unnecessarily rapid clogging of the sand results, with consequent increase in frequency of cleanings.

The method of underdraining these Ilion beds is the same as that in use on some of the newer London plants, and "consists of two courses of brick laid dry, the bottom course being of brick laid end to end, in lines at right angles to the main collecting drain, with spaces equal to the width of a brick between the lines; a second course of brick being laid at right angles to the first, and as closely as possible."

Very excellent drainage is thus secured, upon a plan operating similarly to the agricultural tile-pipe already mentioned.

When a battery of several filters is under construction, it is very desirable that the separate beds be so arranged as to permit of the flow being watched from each one individually, otherwise the general filtrate might be damaged by the poor working of a single member of the group, and no means would exist of detecting and remedying the evil. An interesting table, illustrating this point, is given on page 134.

An important departure from the established type of open filter-beds has recently been made at Lawrence, Mass., after a design, furnished by Mr. H. F. Mills, which takes advantage of the benefits derived from intermittent filtration. The area of the bed in question is 2½ acres and its proposed daily capacity is 5,000,000 U. S. gallons.

In this plant, both the bottom of the containing reservoir and the surface of the filtering sand have transverse ridges, notably higher than the depressions between them; the ridges of the bottom corresponding to the depressions of the sand-surface. The water is admitted along the depressions in the sand-surface, in concrete gutters laid for a short distance thereon, and gradually overflows the surface until the sand-ridges are covered by a foot.

The underdrains are of tile-pipe, laid with open joints, and covered with graded coarse materials. The filtered water is pumped to the consumers, and the running of the pumps and the opening or closing of the inlet are so arranged as to permit of the filtering-sand being entirely drained once in each twenty-four hours, whereby thorough aeration is secured.* The cost of the filter has been about $67,000.

* Excellent as are the results reported from the Lawrence filter, it is very questionable if they be better than those to be obtained by continuous filtration.

The following is the latest report of its efficiency:

	Bacteria per cubic centimetre.	
	Unfiltered.	Filtered.
December, 1894	23,800	364
January, 1895	18,700	206
February, "	15,040	283
March, "	20,770	405
April, "	8,420	84
Average	17,350	268

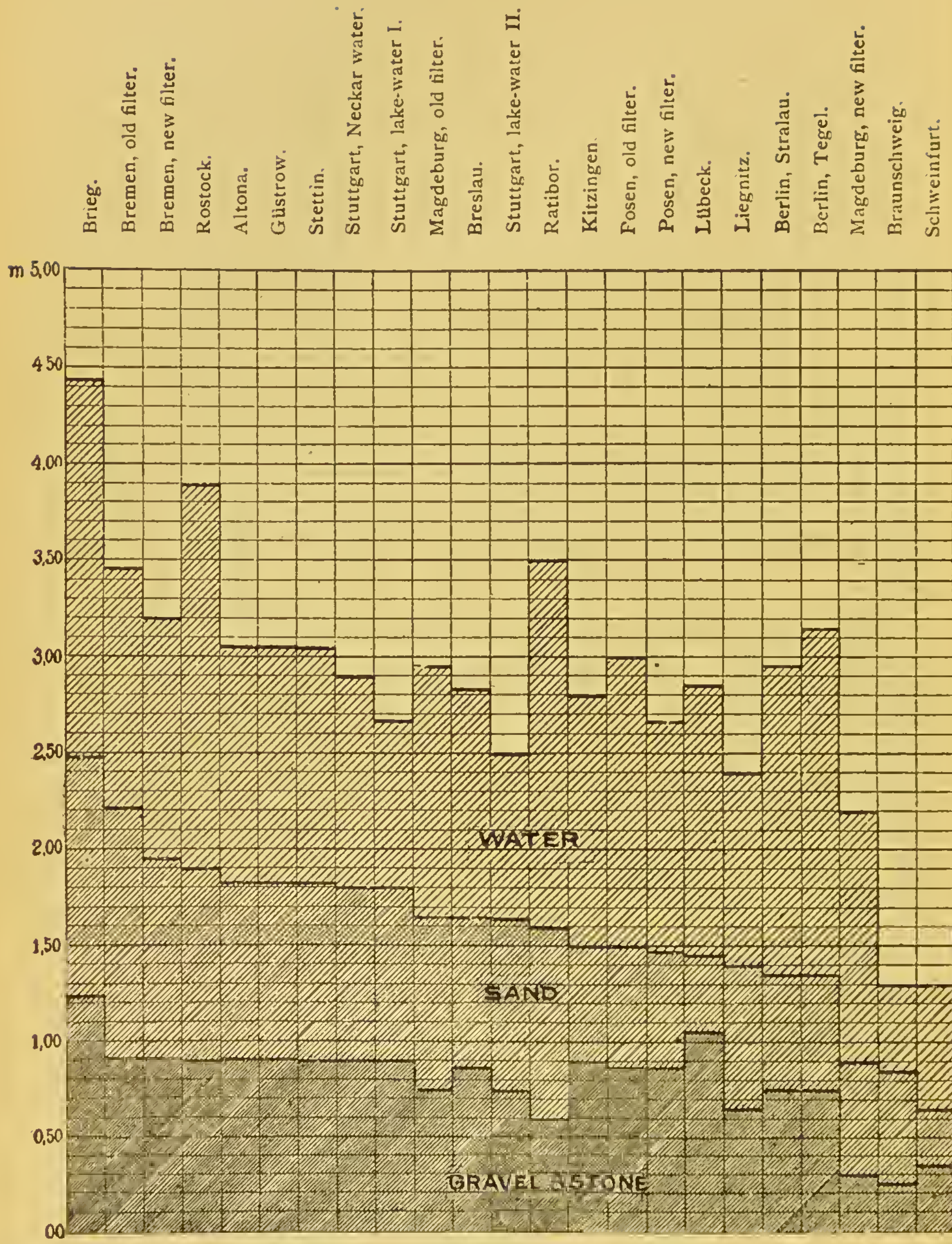
Average per cent of bacteria removed 98.46

The depths of water permitted upon filters of the English type are almost as various as the compositions of the beds themselves, as is illustrated by the diagram on page 114.

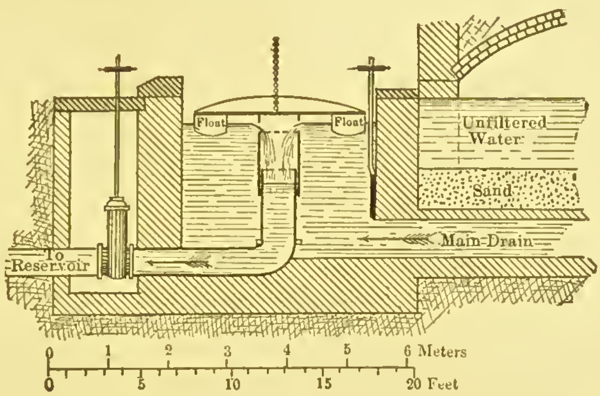
Three and a half to four feet of water may be taken as the depth most commonly in use, and it is important that this depth, when once determined upon, should be maintained a constant. At Hudson, N. Y., the head of water varies exceedingly, running from a few inches to over six feet. Such inequality as must result in the rate of filtration cannot but cause wide differences in the purity of the filtrate.

With many of the more modern filters the rate of delivery of filtered water is independent of the depth of water on the sand, being controlled by an effluent regulator, an excellent form of which was devised by Lindley for the Warsaw works, and is shown on page 115. The outflow takes place through the horizontal slits under a head which is maintained constant by means of the floats attached to the upper end of the cylinder which telescopes the fixed outlet.

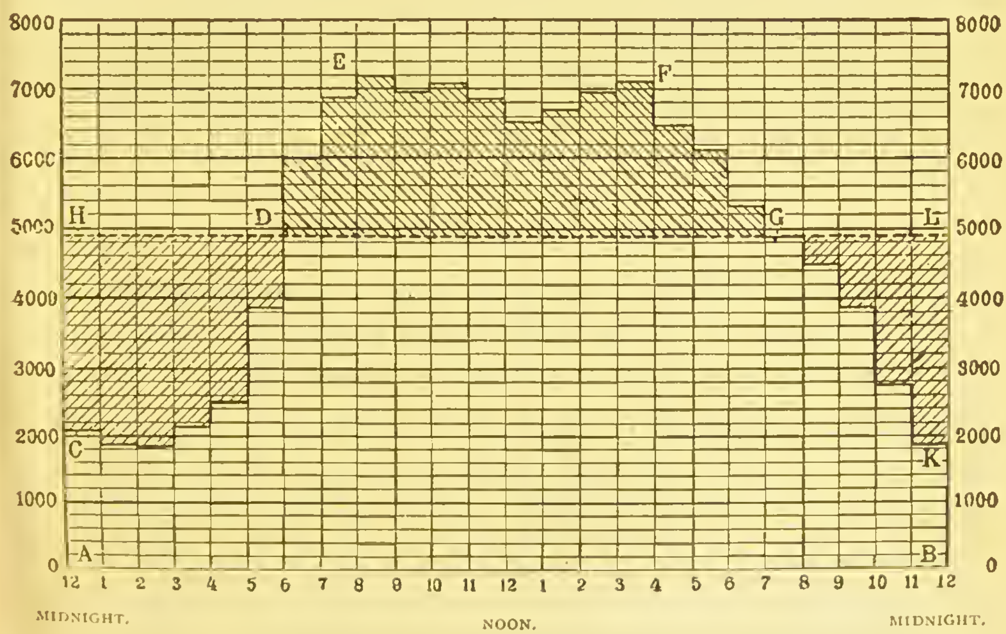
Aeration of the bed, so essential when treating sewage, is hardly necessary when dealing with water, which carries in solution enough oxygen to do all the work required.



COMPOSITION OF FILTER-BED, AND DEPTH OF WATER (IN METRES) FOR SUNDRY GERMAN CITIES. (KÜMMEL.)



EFFLUENT REGULATOR. (LINDLEY.)



VARIATION IN HOURLY CONSUMPTION OF WATER AT BERLIN, STATED IN CUBIC METRES. (FRANKEL).

By use of some such device as Lindley's, associated with a simple overflow-pipe to correct errors from too deep flooding of the bed, constancy in rate of filtration can be assured, a point of material importance in the proper management of a filter.

Of course, inasmuch as no city uses a constant quantity of water during each hour of the twenty-four, it becomes necessary, in order to permit the filtration to go on with regularity, to provide a pure-water reservoir large enough to store the filtered water accumulating during the hours of the night, and from which may be furnished the supply required during the day, when the rate of filtration is not equal to that of consumption.

To show how the hourly consumption may vary in a large city, the diagram on page 115, taken from a recent report, indicates the variation for the city of Berlin.

Considerable difference is noted as to the amounts of water permitted to pass the sand during twenty-four hours, as is shown by the table given below, representing the delivery of some well-known European beds:

RATES OF FILTRATION.*

	U. S. Gallons per acre per day.	U. S. Gallons per square foot per day.	Vertical Inches per hour
Berlin (tegel)	3,179,880	73½	5.0
Oporto	13,895,640	319	21.3
Zurich	7,492,000 to 10,672,000	172 to 245	11.5 to 16.4
Stuttgart	2,134,440	49	3.3
Altona	2,613,525	60	4.0
Liverpool	2,613,525	60	4.0
London: Chelsea	2,178,000	50	3.3
London: East London	1,655,280	38	2.5
London: Grand Junction	2,570,000	59	4.0
London: Lambeth	2,700,700	62	4.1
London: New River	2,570,000	59	4.0
London: Southwark	1,873,000	43	2.7
London: West Middlesex	1,655,280	38	2.5

* The Massachusetts experiment station reports the following average per-

The best practice places two and a half million U. S. gallons per acre per day, or four vertical inches per hour, as the limit, beyond which the rate should not be pushed.*

By direction of the Imperial Board of Health, the maximum rate of filtration has been fixed in Germany at 4 inches per hour (i.e., 8 feet per day, or 60 gallons per square foot of surface).

Mr. Bertschinger reports that at Zurich the rate of filtration varies from 9 to 44 feet per day.

In very carefully conducted experiments Kümmel, of Altona, found that the number of bacteria per cubic centimetre, while the filter was passing 4, 8, and 16 feet per day, was:

At 4 feet per day	11 to 97
" 8 " " "	5 " 79
" 16 " " "	7 " 72

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centage of bacteria remaining in the filtrate, when filtration is conducted at the following rates:

0.5 million gallons per acre daily	0.010 per cent bacteria remain
1.0 " " " " "	0.048 " " " "
1.5 " " " " "	0.067 " " " "
2.0 " " " " "	0.088 " " " "
3.0 " " " " "	0.356 " " " "

Recent experiments at Lawrence have resulted in the following very high rates of duty for the sewage-filters: "Briefly stated, they find that by running the sewage through 5 feet of gravel the size of buckshot, through which a current of air is passing, and then turning the sewage upon the sand-filter, a combined rate of filtration for the gravel and sand of 320,000 gallons per acre per day was secured, and this with a very perfect purification, 95.5 per cent of the organic matter and 99.8 per cent of the bacteria being removed. It is notable that fully three fourths of the organic matter was removed in the gravel tank." —*Engineering News*, Nov. 29, 1894.

* The necessity of limiting the daily delivery of a filter to the above quantity is questioned by the Massachusetts Board of Health in an investigation just published. They find that while such a rate is proper for new filters, a much higher delivery may be assigned to those which have been in service during a long period, "owing apparently to a more extended accumulation of gelatinous films within the main body of the filtering material." There may be conceived to exist "a necessary period of biological or chemical construction as truly as the more obvious case of a necessary period of engineering construction." (Mass. Bd. Health, 1894, 609.)

In consequence, although he accepts the *dictum* of the board of health, he considers the question of the proper rate of filtration as not entirely closed.

For the purpose of cleaning a filter of the English type, a gang of laborers is set to work upon the drained bed, and by means of sharp shovels they pare off the upper half inch of sand and pile the same into small heaps, whence it is removed by wheelbarrows to the sand-washer. This thin upper layer of sand (the *Schmutzdecke* of the Germans) contains the material separated from the water by filtration. It is quite compact, and is so distinctly separated from the sand below as to make the work of its removal very simple. It is liable to be quite membranous in character, and its imperviousness to water is what causes the filter to become "dead" and require cleaning.

Beyond the mere gradual accumulation of suspended matter strained from the water, the claim is made that the *Schmutzdecke* is in part composed of slimy, jelly-like material, produced through bacterial agency, which serves to entangle and hold suspended substances of all kinds. As we shall see further on, the makers of the automatic filters attempt to imitate such action by the use of alum.

The frequency with which the filters have to be cleaned depends upon the condition of the water being filtered, and, for the same water, the condition will vary greatly with the time of year and character of the season. Thus, the London beds experience difficulty from March to July, becoming during those months quickly clogged with fish-spawn, which arrests filtration, and at times renders it necessary to remove the water from the top of the filter before the obstruction can be taken off with rake and shovel.

From July until October another difficulty, scarcely less

serious, is the growth of vegetation, which begins upon the bottom.

Roughly stated, it may be said that a filter becomes "dead" (i.e., nearly impervious to water), and consequently demands cleaning, once every three or four weeks in summer and about half as frequently in winter; but it is not possible to lay down hard and fast general rules applicable to all filters. So many variable quantities enter the consideration, that the question of proper time for scraping must be answered for each filter by itself, basing decision upon intelligent observation of the number of bacteria removed, the rate of flow, and the obvious general efficiency.

It is not customary, nor desirable, to have the newly scraped filter remain out of service until the sand removed is washed and returned to its place; for the fine sand-layer should be thick enough to permit of a number of successive scrapings without impairment of its efficiency; therefore the sand taken off during a series of parings is all washed and returned at one time.*

As already stated (page 100), the upper sand-layer must not be reduced below a thickness of twelve inches by these successive scrapings, and it is better to stop much short of this limit.

Considerable variation is found among the methods employed to accomplish the cleaning of the dirty sand—from the refined system in use at Liverpool to the comparatively simple and less efficient process employed at London. At the latter place, washing is undertaken by the use of a simple hose played upon the sandheap, suitable inclined drains carrying off the wash-water. At Liverpool and other places

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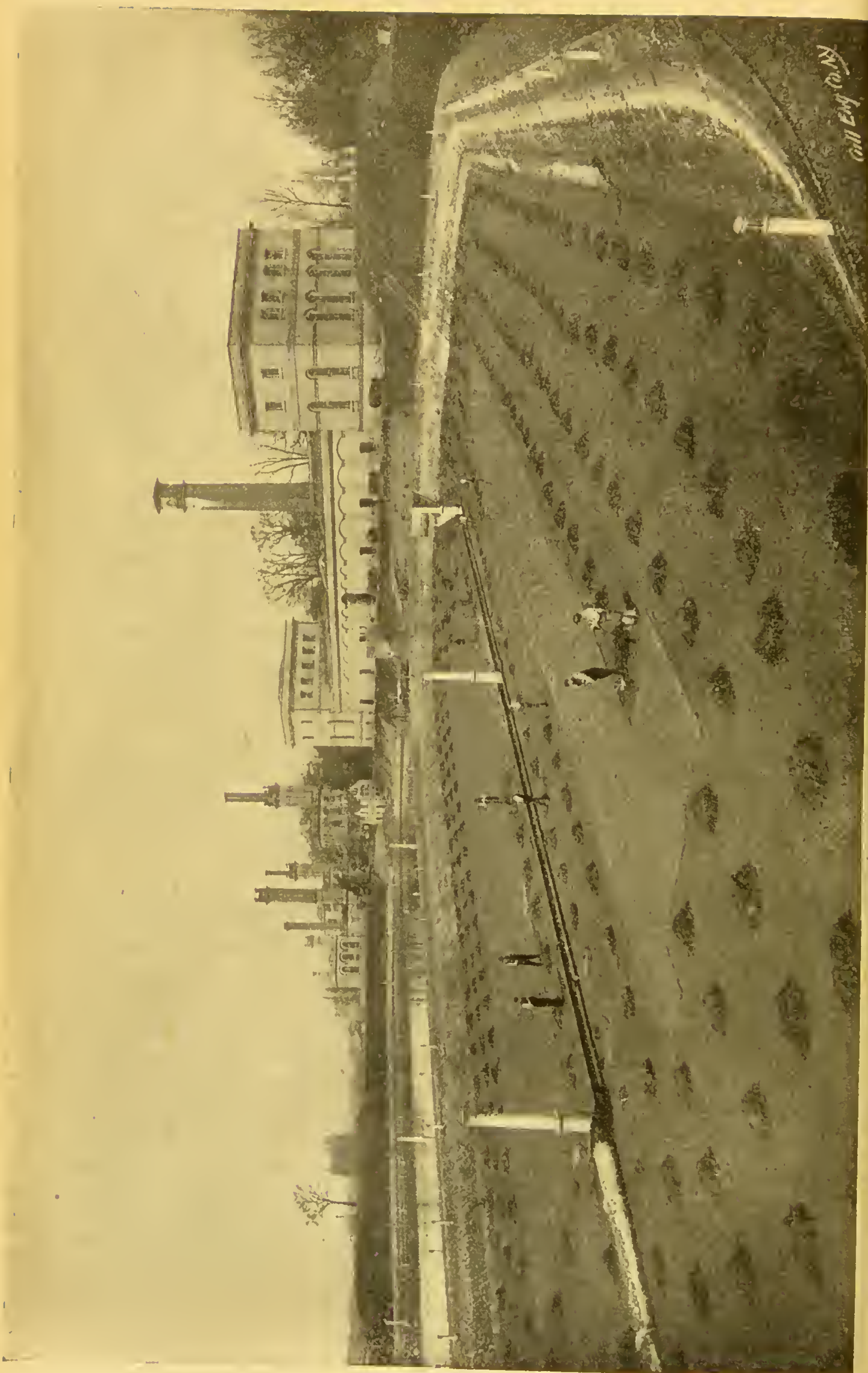
* Lawrence experiments show that the best practice is to build a filter with so deep a sand-layer as to permit the successive scrapings to cover a period of a year before renewal with clean sand. Otherwise there is a tendency for fine material to form sub-surface clogging at the junction of the old and the clean sand. (Mass. Bd. Health, 1894.)



rotary sand-washers scour and clean the sand with great thoroughness.

At Hudson, N. Y., the new filter was built with an arrangement by which the water from the pumping-engines could be delivered at the bottom of the bed, if so desired, and forced upward through the filtering-materials. It was hoped to thus float off the "dirt-cover" from the upper sand, and thereby save labor in cleaning.

After a thorough trial the method was pronounced a failure, and abandoned. But even had the dirt-layer been successfully floated off, this mode of procedure would have been a very questionable one; for the water introduced into the lower levels of the bed by the reversed current was unfiltered, and must shortly have polluted the filtering materials; and even had the water been pure, the delivery of it, direct from the force main, would certainly have tended to the formation of channel-ways in the sand, a result very fatal to good filtration.

The cost of cleaning a filter and washing the removed sand depends upon the plan adopted for the latter work, and upon the local price of labor.

The following figures give the cost for cleaning per million U. S. gallons of water filtered:

London	$0.86
Liverpool	1.14
Ilion, N. Y	0.82
Hudson, N. Y	0.88
Poughkeepsie, N. Y.*	2.78

* The statement of the present superintendent is: "For the thirteen years that these beds have been under my supervision, 1881 to 1893, inclusive, the total expenditures for all purposes including repairs, purchase of new sand, cleaning beds, and washing sand have been $22,715. During this period 7,716,997,902 gallons of filtered water were pumped to the city, giving a total average expenditure of $2.94 per million gallons." This is, of course, exclusive of interest charges.

The fairest of the above figures is that for Liverpool, inasmuch as the American plants named are but very small ones; but it must be remembered that some correction is proper, to allow for the difference in price of labor before comparison is made. In Liverpool the laborer receives 95 cents per day, as against $1.50 paid at Hudson, N. Y. The Liverpool sand-washing is very carefully and completely done.

Outside of the interest items upon price of plant and price of needed land, there is not much beyond the cost of cleaning to charge against filtration, because the question of fixed salaries would enter into the water-works expense bill in pretty nearly the same figures whether a filter-plant were established or not. Charge for maintenance of pumps would naturally be excluded from filtration charges.

The cost of running the new filters at Hamburg, Germany, is twenty-one marks (about $5) per million U. S. gallons filtered water. This sum, however, includes pumping and pump repairs.

The cost of operating the filters (covered and open) at Zurich, Switzerland, per million U. S. gallons of water delivered, has been given by Preller as follows: *

	Covered.	Open.
Superintendence	$0.15	0.19
Cleansing and replenishing sand	0.16	0.28
Breaking ice	....	0.03
Renewing filtering material	0.17	0.31
Maintenance, intake and mains	0.08	0.09
Repairs and sundries	0.03	0.04
6% interest and sinking fund	5.47	5.79
	6.06	6.73
The relative yield per acre per day in U. S. gallons is given as	7,800,000	6,500,000

* Proc. Inst. C. E., cxi.

These rates of filtration are very high, but are often exceeded by these same filters. (See page 116.) As a consequence, the cost of the water per million gallons is lowered.

Before consenting to the large outlay of funds required for filtration by the English filter-bed system, the tax-payer very properly asks what efficiency may be looked for from such a construction.

The best answer to this question is to quote the recorded duties of some existing plants.

At Hudson, N. Y., the author found the following results from samples taken May 12, 1894. Results are stated in parts per million:

	Filtered.	Unfiltered.
Free ammonia	.014	.070
Albuminoid ammonia	.106	.140
"Required oxygen" (Kubel)	4.100	6.500
Chlorine	3.000	3.000
Nitrogen in nitrites	zero	trace
Nitrogen in nitrates	.100	.100
Total solids (dried at 212° F.)	80.500	83.500
Loss on ignition	34.000	37.500

Bacteria per cubic centimetre	57	787
Bacteria removed by filtration	92.76 per cent	

The bed at the above date was evidently not doing its best work, in view of the lack of increase in the nitrates. As has already been noticed (page 113) this filter is run with considerable lack of uniformity.

Percy Frankland reports that, as an average result for

three years, the London filters removed 97.6 per cent of the bacteria present in the unfiltered water.*

The London official report for August, 1895, is:

Unfiltered......	1720
Filtered.............	34
Bacteria removed.............	98.03 per cent

As an illustration of the efficiency of the Stuttgart filters, the following counts are given of the number of bacteria per cubic centimetre in the filtered and unfiltered Neckar water:

	August.	September.	October.	November.	December.
Unfiltered.................	8942	1310	918	2712	3462
Filtered.................	16	52	54	517	53
Per cent remaining......	0.17	3.9	5.9	19.1	1.5

In examining these figures it would appear to be in a measure true that the percentage of purification varied directly as the extent of original contamination, and our

* During the year 1888 the efficiency of the filters running on Thames water stood as follows:

		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Average.
Thames, unfiltered....		92000	40000	66000	13000	1900	3500	1070	3000	1740	1130	11700	10600	....
Chelsea..............		127	152	54	38	43	63	37	32	36	14	82	71	62
Middlesex....		60	146	408	158	71	56	27	11	26	33	31	16	88
Southwark..		177	766	742	47	47	24	35	27	106	35	167	136	192
Grand Junction.......		90	349	617	56	77	40	15	4	20	16	25	208	126
Lambeth		189	820	321	157	64	140	55	33	92	27	126	151	181
Reduction, per cent..		99.9	98.9	99.4	99.3	96 8	98.1	96.8	99.3	96.8	97.8	99.3	98.9	98.4
London Water in general for 1895.	Unfiltered.	......	7334	9236	9175	4070	7625	3425	1720	2432	2603	....	......	....
	Filtered.	......	44	41	46	18	19	30	34	62	68	......	......	....

thoughts at once revert to what is claimed for the influence of "bacterial jelly" (page 118) in arresting the passage of germs.* At least such figures support Koch's view that a well-managed filter should deliver a filtrate containing less than one hundred germs per cubic centimetre, irrespective of the number in the unfiltered water.

No better illustration can be given of what sand-filtration is capable of accomplishing than is presented by the record of the ten filters at Altona, Germany, during the month of February, 1893. The average number of germs per cubic centimetre in the raw Elbe water for that month was 28,667, whilst the corresponding average for the filtered water was only 90; showing a removal, by filtration, of 99.69 per cent of germs of all kinds.

What this removal meant for the city of Altona, during the cholera outbreak at Hamburg in 1892, has already been touched upon (page 55) and may be epitomized in a single word—"safety."

The filter at Lawrence, Mass., belongs to a class of its own, and, by its intermittent action, seeks to derive a large fraction of its efficiency from a thorough development of the nitrifying organism within the bed, and thus burn the organic nitro materials to nitrates. A record of its work may be suitably given here, and best in the words of H. F. Mills, its designer:

"The removal of bacteria is not merely a straining process; it is accomplished by making conditions unfavorable to the life of bacteria in the passage through the filter, which conditions grow with the proper use of the filter. In the

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* Piefke, of Berlin, showed that sterilized sand possessed no power of removing bacteria from water, and that the important factor in efficient filtration is the coating of slime which gradually envelopes each individual sand grain, and forms an adhesive surface. In this connection see also Mass. Bd. Health, 1890, 848.

first three days 75 per cent of the number of bacteria applied came through the filter. In the next three days 30 per cent came through, but in the first week in October only 4 per cent came through, and in the next week 2 per cent; that is, during the first three weeks' use the number of bacteria in the effluent rapidly decreased to 2 per cent of the number applied, and from that time to the present, excepting on two occasions, when work on the filter or in the pump-well interfered with the results, the effluent from the filter has contained 1.7 per cent of the number of bacteria contained in the river-water, the filter having removed 98.3 per cent of all the bacteria in the water applied to it.

"But the result given to the people is better than this. It appears that with the removal of those parts of the organic matter that are easily oxidized, the food material of the bacteria has been removed, and as the water flows on through the reservoir and through the pipes,* the conditions of life are still unfavorable for the bacteria, and they go on decreasing, so that the numbers found at the outlet of the reservoir are but 1.2 per cent of the numbers in the river-water; and at the tap in the City Hall the numbers of bacteria found are but nine-tenths of one per cent of the numbers in the river-water. More than 99 per cent of all of the bacteria of the river-water has been removed."

In the following table are given the average results of the analyses of chemical samples and of corresponding bacterial samples, collected from different parts of the Lawrence waterworks, from October 13, 1893, when the filtered water had apparently reached all points in the service pipes, to December 15:

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* This favorable influence of the mains of a city is referred to again upon another page.

	Ammonia.		Chlorine.	Nitrogen as		Oxygen Consumed.	Bacteria per Cubic Centimetre.	Per Cent of Bacteria Removed.
	Free.	Albuminoid.		Nitrates.	Nitrites.			
River	.084	.202	2.2	.14	.003	3.9	14,000	......
Effluent from filter	.068	.109	2.2	.31	.005	2.8	258	98.16
Reservoir outlet	.033	.133	2.3	.27	.001	2.7	113	99.19
City Hall tap	.023	.122	2.3	.30	.000	2.5	87	99.38
Experiment Station tap	.019	.110	2.2	.31	.000	2.3	93	99.34

[Parts per 1,000,000.]

How Lawrence has benefited by the action of this filter may be judged from the fact "that the mortality from typhoid fever has, during the use of the filter, been reduced to 40 per cent of the former mortality, and that the cases forming nearly one half of this 40 per cent were undoubtedly due to the continued use of unfiltered river-water drawn from the canals."

In referring to the action of the Lawrence filter, Mr. Mills says:

"The question may arise, if water contains so much air why does not nitrification take place in a reservoir? The reason is that nitrification will not take place unless the water with the air comes in contact with certain bacteria, which in some unknown way cause the process to be carried on. These bacteria attach themselves to the grains of sand of the filter and remain there, and when air is present they can in a short time cause the nitrifying process to be carried on so completely that nearly all of the organic matter in the water is burnt up, and with this burning the disease germs in the water are killed." *

* In the experimental filtration of sewage at Lawrence, through sand, it was found that nitrification did not begin until the temperature of the effluent (in winter) rose to 39° F., but that after nitrification was once established a

The thoroughness with which nitrification, and consequent purification, can be accomplished, by filtration through shallow beds of even very coarse material, has been perfectly worked out and demonstrated by the admirable investigations of the Massachusetts experiment station, and one important point elucidated is that a small amount of oxygen (1 to 3 per cent) in the air of the filter is as effective as a larger quantity.

It would be impossible here to devote space to a proper recounting of the valuable work of the Massachusetts State Board of Health upon the subject of filtration, but a few words from a report of G. W. Fuller, one of the bacteriologists in charge, will give an idea of the efficiency with which bacteria may be removed by five feet of filtering-material intelligently managed:

"The actual efficiency of the filters was tested by the application of typhoid fever germs and other important kinds of bacteria, and observations on their passage through the filters. The pure cultures of the micro-organisms were grown in dilute bouillon solutions. Twenty-five or fifty cubic centimetres of these solutions, containing millions of germs, were applied to the filters in a small quantity of water, and the effluent was examined at frequent intervals for several days. Fifty-five such experiments were made during the first five months of 1892, with these average results:

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reduction of temperature to 35° F. did not stop the process. Also, that bacteria decreased rapidly when nitrification commenced.

The presence of soil, as was formerly supposed, is not necessary to a good filter, in fact, it may act disadvantageously. Sand alone has been found to give excellent results.

Number of filters tested	11
Number of experiments with typhoid-fever germs	22
Number of experiments with *B. prodigiosus*	19
Number of experiments with *B. coli communis*	14
Average rate of filtration, gallons per acre, daily	1,350,000
Number of bacterial determinations	914
Average number of bacteria per cubic centimetre applied	104,200
Per cent removed	99.48

[The extreme limits in the rates of filtration in the several experiments were 280,000 and 2,600,000 gallons per acre, daily.]

"These experiments were very severe tests upon the efficiency of the filters in removing bacteria, because the number applied was probably greater than would occur in practice, and furthermore the organic matter introduced with the bacteria served them as a food material. The experiments made during the latter portion of the year are much fairer, because the bacteria were applied in small and long-continued doses at frequent intervals, and the food material applied with them did not increase the organic matter in the river-water beyond the limits of variation observed from time to time in the amount originally present. The species of bacteria used was *B. prodigiosus*, on account of its easy and reliable differentiation, its similarity to the typhoid fever germ in its mode of life in Merrimac River water, and the fact that it has never been found native in this country. In the following table are summarized the average results of daily experiments from September 16 to December 31, 1892:

Number of filters experimented upon	11
Number of bacterial determinations	2,372
Rate of filtration, gallons per acre, daily	1,700,000
Average number of *B. prodigiosus* per cubic centimetre applied	5,700
Per cent removed	99.87."

With reference to the portions of the filter doing the greatest duty in germ removal, the Lawrence experiments show the following numbers of bacteria found in a grain of sand at successive depths:

Depth from Surface.	Bacteria per Grain of Sand.
¼ inch	1,100,000
½ "	320,000
1 "	140,000
2 "	21,000
4 "	4,000
6 "	1,600

The filters here referred to were small ones constructed for experiment. Among the interesting records of their achievements, it is especially worthy of note that but very few of the typhoid germs, applied to them in the form of pure cultures diluted with water, were able to pass into the filtrate, and that in many cases the effluent was entirely free of the specific organism, as is shown below:

Material of Filter.*		Size of Sand in Millimetres, Ten per cent finer than	Rate of Filtration, U. S. Gallons per acre, daily.	Per cent of Applied Typhoid Germs Removed.	Kind of Filtration.
Sand (feet)	Loam (inches)				
5½	0	.48 (coarse mortar-sand)	980,000	99.95	Intermittent.
"	"	"	1,000,000	99.00	"
"	"	"	860,000	99.90	"
5	2	.26	340,000	100	"
"	"	"	320,280	100	"
"	"	"	280,000	100	"
"	"	"	460,000	100	Continuous.
"	"	"	400,000	100	"
"	"	"	400,000	100	"
5	1	.19	1,560,000	100	Intermittent.
"	"	"	2,140,000	100	"
"	"	"	2,740,000	98.40	"
"	"	"	1,540,000	99.84	"
5	1	.19	1,540,000	100	Continuous.
"	"	"	2,100,000	97.22	"
"	"	"	1.540,000	99.86	"
5	0	.19	1,540,000	100	"
2	0	.19	1,500,000	99.16	"
1	0	.19	1,540,000	99.00	"
1	1	.19	1,480,000	98.44	"

* The filters here studied were of an experimental type only. For practical

Upon these results the report from which they are derived comments: "Deeper filters are much safer than shallow ones; low rates are safer than high rates; and, at the same average rates, continuous is quite as effective as intermittent filtration for the removal of bacteria." More recent investigations were made by the board in 1893, upon the efficiency of much coarser material, permitting a much higher rate of filtration. Some of the results are here given:

Depth of Sand. (Inches.)	Method of Operation.	Average Rate of Filtration. (Gallons per Acre, Daily.)	Average Per Cent of Applied Bacteria which Appeared in the Effluent.	
			Water Bacteria.	*B. Prodigiosus.*
60	Continuous.	7,660,000	1.48	0.171
60	"	7,700,000	1.19	0.148
60	Intermittent.	3,740,000 [6,545,000]*	1.50	0.210
12	Continuous.	3,700,000	2.34	0.337
60	Intermittent.	3,660,000 [6,405,000]*	3.13	0.463
60	"	2,900,000 [5,075,000]*	1.83	0.366
60	Continuous.	5,550,000	1.04	0.183

As an interesting illustration of the purifying powers of sand-filters, the following comparisons are made between the waters of wells actually in use at Lawrence and the effluents from filters filtering city sewage.†

purposes it is very unadvisable to place fine material, such as loam, below the surface. Clogging is sure to result in a location difficult to reach, and the filter eventually passes out of service.

* The rates of filtration enclosed within the brackets are for the time when water was actually applied; the other rates are averages for the whole time, including the periods of rest.

† Mass. Board Health, 1890 [2], 599.

	In Parts per million.					Bacteria per Cubic Centimetre.
	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Nitrogen as Nitrates.	Nitrogen as Nitrites.	
Tank 1, for two months............	.313	.272	48.3	17.8	.008	549
Well-water, Atlantic Street.........	1.410	.155	80.8	23.7	.024	4370
Tank 13, for six months............	.011	.105	72.8	12.5	.004	76
Well-water, Hampshire Street......	.078	.118	75.1	20 0	.007	128
Tank 6, for three months...........	.036	.104	49.8	16.6	.002	678
Well-water, Andover Street.........	.184	.046	27.9	15.0	.028	46
Tank 4, for two months	.025	.108	37.2	7.5	.002	20
Well-water, Salem Street...........	.070	.086	76.7	14.0	.014	447
Tank 2, for four months............	.007	.065	39.8	7.1	.000	17
Well-water, Lowell Street..........	.012	.070	71.1	21.0	.000	27
Tank 7, eight months...............	.014	.063	40.4	10.6	.000	7
Well-water, Haverhill Street........	.022	.050	24.4	5.5	.016	344
Tank 6, for six months.............	.014	.074	45.1	11.1	.001	319
Well-water, Mechanic Street..	.016	.076	52.9	42.0	.000	240

The sewage effluents are certainly at least as good for potable use as some of the above waters.

Very marked influence was noted at Altona, upon the germ contents of the filtered water, as a result of scraping the bed of its "dirt-layer." (See table on page 134.)

The table gives the daily performance of the Altona filters during February, 1893, and suggests the wisdom of the policy, in vogue at various places upon the continent, of wasting the filtrate for a time, immediately after cleaning the filter.

The necessity for this waste, as indicated by the Altona results, does not accord with the experimental experience obtained at the Lawrence experiment station, nor do they there find any appreciable diminution in the bacterial efficiency of the experimental filters due to scraping, provided there be no mechanical disturbance of the main body of the sand.*

* Mass. Board of Health, 1893.

NUMBER OF GERMS CONTAINED IN THE WATER OF THE ALTONA WATER-WORKS.

February.	Filter. 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	R.W.	E.W.
1	....				....			832	....		154	28,520
2	88				212			550	908		142	35,340
3	106				374			R.	76	636	110	40,920
4	123				276			208	96	530	146	31,360
5	176				206			544	84	362	105	33,480
6	418				306			401	82	334	68	39,680
7	234				204			446	94	R.	94	41,660
8	50	22	40	24	28	136	146	368	84	152	130	28,560
9	48	28	R.	32	54	194	152	182	64	122	72	44,140
10	108	50	88	20	28	120	98	110	58	112	126	42,160
11	68	60	76	78	36	140	R.	126	76	204	152	34,100
12	72	58	240	60	38	110	288	80	70	282	82	26,040
13	34	30	560	48	28	82	214	186	86	374	104	24,800
14	40	46	354	24	18	52	164	142	46	364	142	34,080
15	26	28	76	14	18	44	74	48	26	72	49	40,260
16	38	26	84	24	22	52	76	60	R.	120	78	25,420
17	20	36	156	R.	22	48	82	86	324	130	95	26,400
18	26	18	102	54	32	54	112	72	82	126	91	26,440
19	24	20	88	78	28	44	98	82	64	102	70	24,800
20	26	22	70	104	24	36	96	88	34	78	46	19,840
21	20	14	80	68	R.	34	96	44	30	152	50	34,720
22	34	R.	46	62	158	34	68	36	64	*	42	18,250
23	46	246	52	66	138	46	56	54	72	174	68	14,560
24	22	42	32	36	72	22	72	76	34	44	54	11,080
25	18	36	30	28	48	16	48	42	36	38	48	12,360
26	14	20	24	21	34	12	40	36	28	34	32	9,370

R. Cleansing of the filters. R.W. Pure water reservoir.
E.W. Elbe water before filtration. * Experiment failed.

Kümmel, of Altona, fills up the newly-cleaned filter, from beneath, with filtered water, to the top of the sand; runs on the raw water; lets it stand ten or twelve hours, and then starts filtration, with satisfactory results.

When, however, the filter has had new sand placed upon it, the numbers of bacteria in the water have been found as follows:

Before filling up....	42
One day after filling up.......	1880
Two days " " "	752
Three " " " "	208
Four " " " "	156
Five " " " "	102
Six " " " "	84

He insists upon the necessity of wasting the water for several days after such filling.*

A recent critic of the filter-bed system refers to the removal, by the bed, of ninety, odd, per cent of all bacteria present in the raw London water, and then notes that reduction of the typhoid death-rate has been by no means so large. As an explanation of the observed facts, he suggests that the small size of the typhoid bacillus prevents its being arrested by the filter as easily as its larger companions.

In reply, it must be said, firstly: Typhoid fever would not entirely disappear from London, or any other city, were the water-supply absolutely sterile, for the sufficient reason that bad water, although a main cause of the disease, is not the only one. Secondly: Filtration is very far from being a simple straining process; were it so, all bacteria would pass the filter with equal facility, for differences between the several sizes of these extremely minute objects would be small indeed as compared with the spaces between the grains of sand. Whatever its size, the bacterium is caught by the zoöglœa jelly surrounding the grains of sand, or is killed by the adverse conditions set up during nitrification, or both.

For the proper management of a well-constructed filter, so as to obtain the good results of which the structure is capable, Piefke, of Berlin, insists upon (1st) wasting the fil-

* See Am. Soc. C. E., xxx, 334.

trate immediately after each cleaning; (2d) uniformity in rate of filtration; (3d) low rate of filtration.

Beyond these points it would be proper to also require a very slow and careful filling of the sand-voids with clean water admitted through the underdrains after cleaning has been accomplished; for if the water be passed in hurriedly, disturbance of the sand body by the escaping air will assuredly take place, resulting in the passing of bacteria through the channel-ways so formed.

The impure water, after having been run on to the filter, should, according to the best German authority, be permitted to settle for twenty-four hours, and form a thin film of deposit before the filtration is resumed. At the Lawrence experiment station doubt has been expressed as to the necessity for this delay, but final decision has not been reached.

Especial care should be taken that no freezing of the sand take place during the time of cleaning. The difficulty of preventing this is, of course, a question involving climate, and for very cold countries the only solution of the problem is the construction of covered filters.

Where open filters are in use in Europe, the attendants depend upon a careful watching of the weather, and very rapid work during cleaning, to prevent freezing. Should the sand once become frozen, the difficulty is a serious one, for, as was demonstrated at Altona, the water above the sand does not thaw the ice nearly as rapidly as one would expect, and, moreover, thawing takes place unequally over the surface, whereby a discharge of the whole filtrate occurs through only a fraction of the bed, with most unsatisfactory results.

Where the winters are as severe as at Hudson, N. Y., cleaning an open filter is often impossible, and the most that can be done is to keep the ice-cake floating clear of the sand.*

* The filter there in use should unquestionably be covered.

As to the most effective size for filtering-sand, that is yet an open question, and is undergoing experimentation, although at Hamburg the size claimed as best is that of one millimeter (0.04 inch) in diameter of grain.*

Uniformity in the sand is quite as important as size of grain, and especial care should be taken to have this vital point carefully secured.

A modification of the English filter-bed has just been proposed to meet the special conditions found at Philadelphia, where the authorities naturally desire to utilize the existing concrete-lined reservoirs. The plan offered is to partition the reservoirs off into sizes proper for filters, and build upon the floor a suitable supporting rack to hold the bed of filtering-materials; the same to consist of a thin bottom layer of fine gravel, upon which is to rest the usual thick layer of filtering-sand. Filtration is to take place upwards, and washing is to be done downwards, the inlet for raw water and outlet for waste-water being the same. By this arrangement the designer hopes to avoid all complications from ice, the ice-cake being permitted to form freely and float clear of the sand-bed.

During washing a current of air is let into the space underneath the bed, with a view to tumble the grains of sand and break up the sediment, so as to enable it to pass out with the wash-water.

So far as principle is concerned, there may be little difference between upward and downward filtration, but in

* "That sand presents the conditions most favorable for very complete purification of sewage, the finer 10 per cent of whose grains has diameters equal to or less, but not much less, than 0.2 millimetres.

"It was found that heating the sand of a filter to 300° F. or more, and pouring boiling water through it, caused 100 times as many bacteria to pass through it with sewage, for three months, as passed through a similar filter whose sand and first water had not been heated. This appears to be due to preparing the organic matter in the sand and in the water by heat, so that it is a better food for the bacteria." (Mills in Am. Soc. C. E., XXX. 350.)

practice there would be serious objection to the former plan. Much difficulty would be experienced in securing uniformity of work over the whole area of the bed, owing to the impossibility of preventing the dirt-layer falling off in spots, and it is well known that uniform action is of vital importance. It is, moreover, a dangerous practice to foul a filter in a place beyond reach of inspection and repair, for there is no way of determining whether or not the provided means of cleaning are working satisfactorily. The designer is at pains to state that the scouring action of the air and reversed current of water, during cleaning, cannot disturb the proper structure of the bed; but this must be accepted as a doubtful proposition.

MECHANICAL FILTRATION.

Although the rapid filtration of large volumes of water (usually under pressure) through very limited sand-areas is accomplished by appliances patented and controlled by numerous companies, yet the use of such apparatus is so nearly confined to this side of the Atlantic as to warrant the employment of the generic expression "American Filter System."

Roughly outlined, this plan consists in adding to the water to be filtered a minute dose of common alum, averaging between one quarter and one half of a grain per gallon, and then admitting the water to the filter, which is a cylinder of wood or boiler iron, three quarters full, of uniformly fine sand. The carbonates present in the water decompose the alum, with the formation of a white flocculent precipitate of aluminum hydrate, quite jelly-like in appearance.* The action of this aluminum hydrate is much the same as

* For instance, the carbonate of calcium acts as follows:

$$K_2Al_2(SO_4)_4 + 3CaCO_3 + 3H_2O = 3CaSO_4 + K_2SO_4 + 3CO_2 + Al_2(OH)_6.$$

that of the white of egg in clearing coffee. It entangles all suspended matter, disease germs as well as inorganic material, and deposits the same on the surface of the sand, whence it is removed and driven into the waste-pipe by a reverse current of filtered water at the time of cleaning the filter. The cleaning occupies but a short time, not much beyond fifteen minutes, and can be accomplished by a waste of less than ten per cent (usually four per cent) of the daily delivery of filtered water. Thus, it is observed, the mechanical filter produces an artificial inorganic jelly to replace the "bacteriæ jelly" of the English filter-bed, already alluded to on page 124 and 125. In properly managed filters of this type no alum (or, at most, a trace) reaches the filtrate, for only such a quantity is admitted to the water as will be decomposed by the amount of carbonates present.

A further action of the precipitated aluminum hydrate is to unite with the soluble coloring matter of the water, thereby rendering the filtrate colorless. The proper "dose" of alum solution is administered by means of a small automatic measuring apparatus exterior to the filter.*

A detailed description of any of the filters under this class would hardly be necessary here, especially as such information is to be had so readily, by application to any one of the several companies making them; but in place thereof, one or two cuts are inserted representing common forms, and the general method of operation may be judged therefrom. (See pages 140 and 141.)

The general method of placing these filters in gangs for city supply is also worthy of illustration. (See page 142.)

The illustrations above referred to represent filters operating under pressure, and arranged to receive the "dose" of alum

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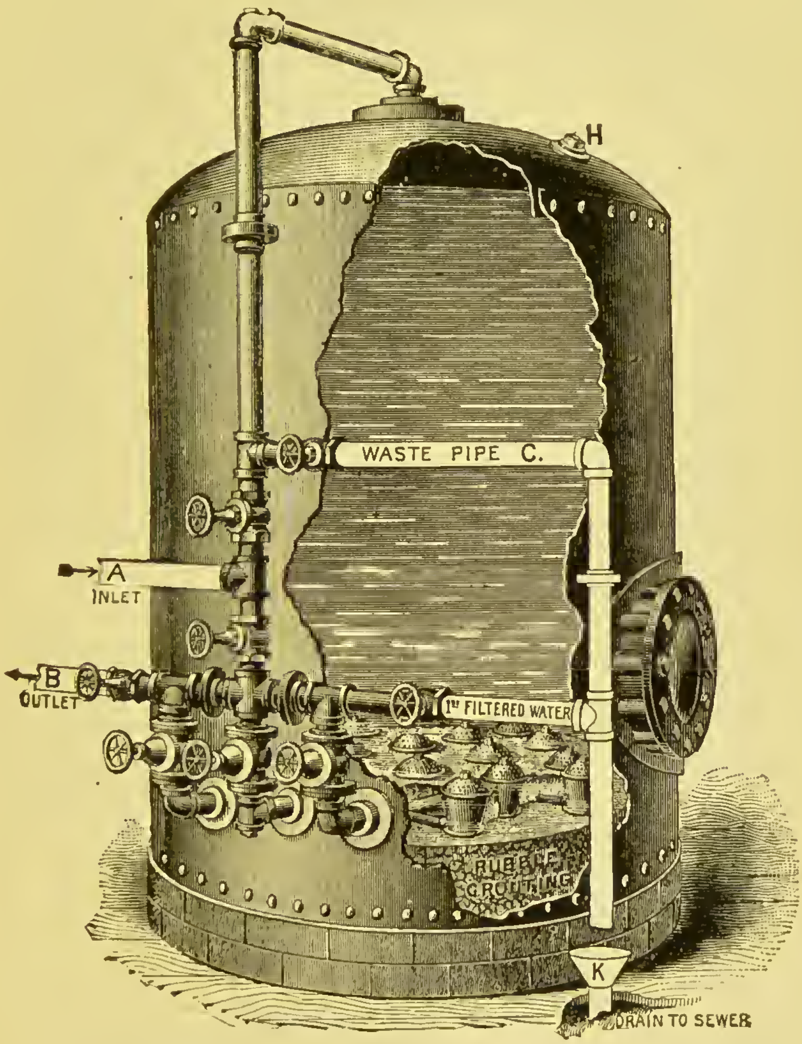
* It must be understood that the use of alum, or some other suitable coagulant, is imperative in these filters. Filtration through sand alone, at so high a rate, would be but a straining action incapable of efficient removal of bacteria.

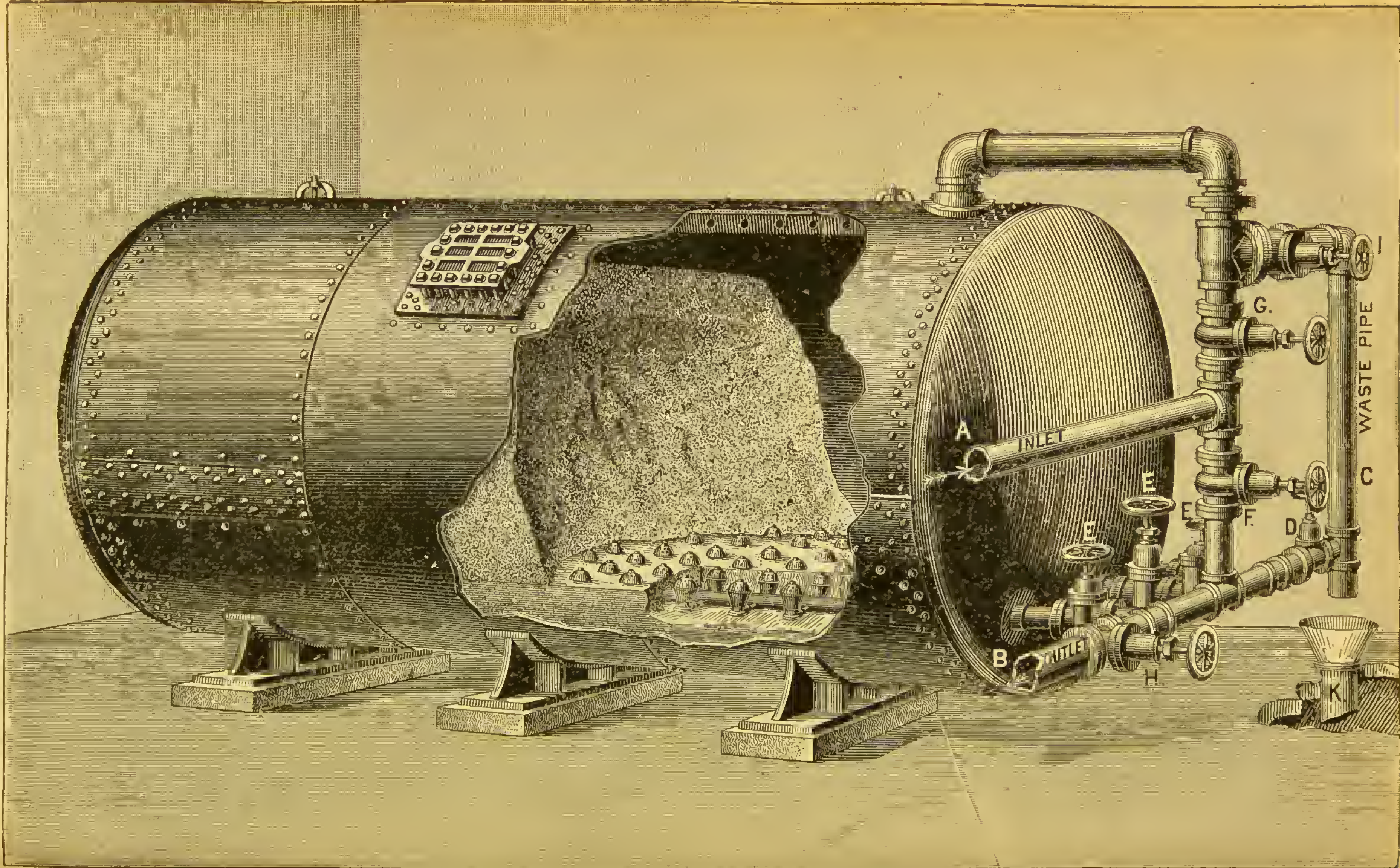
immediately before the filter is reached by the entering water. On pages 142 and 143 are given illustrations of a kindred form of filter which is open at the top, and which possesses a settling-tank between the point where the alum reaches the water



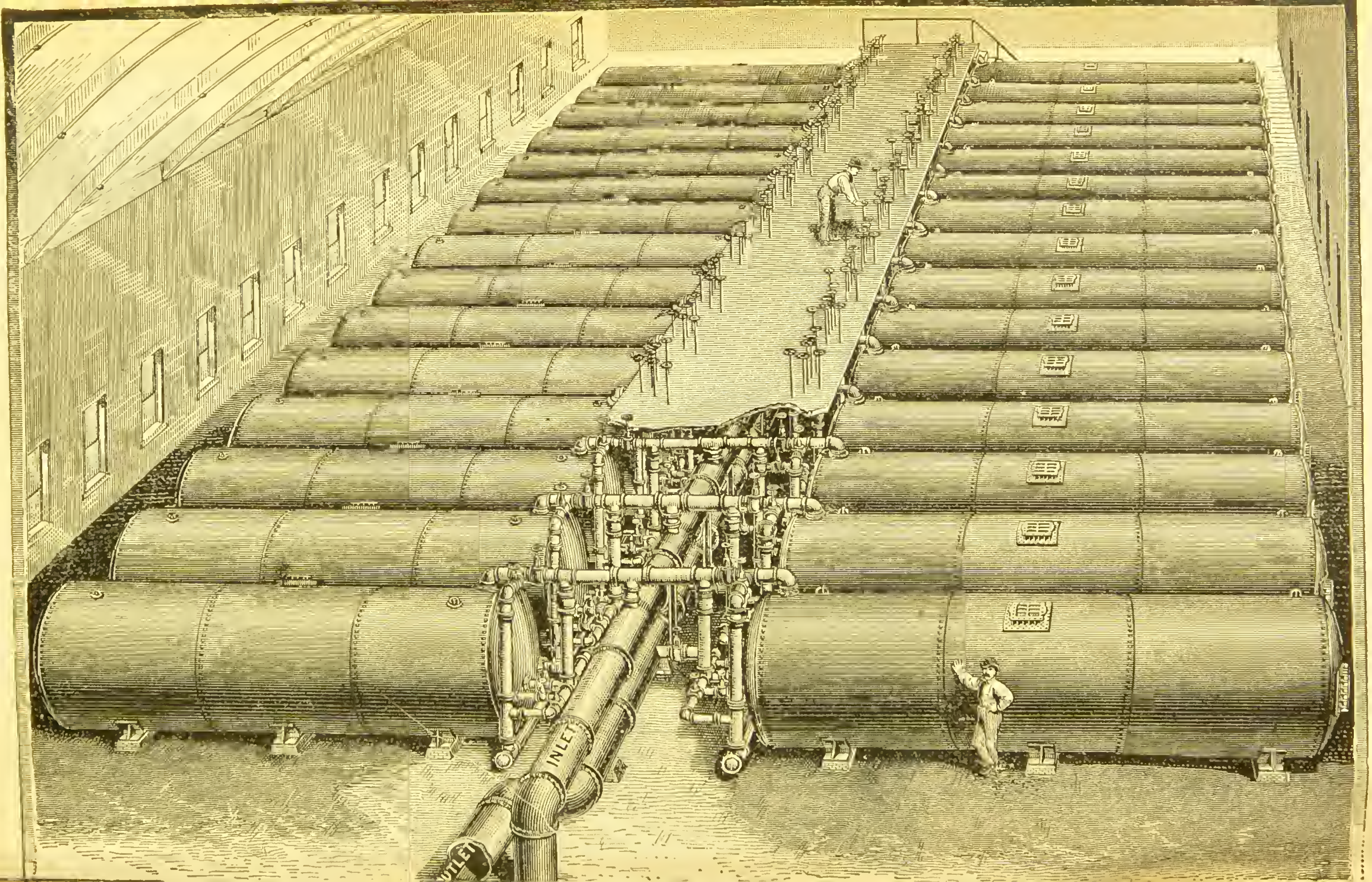
AUTOMATIC PRESSURE-FILTER.

and the filter proper. The sand-bed in this filter is quite shallow, and is stirred up, during the process of cleaning, by revolution of the rake shown in the drawing.

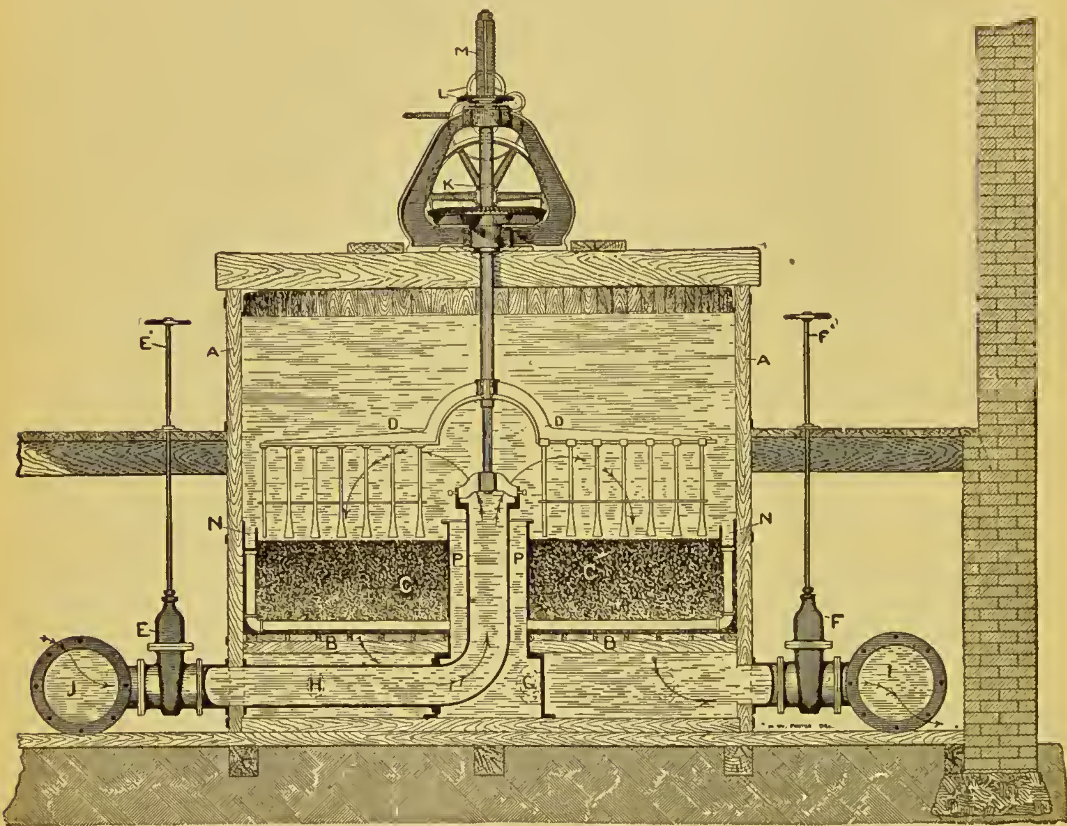
In attempting to give the cost of a large plant for mechanical filtration, it must be remembered that the case is



WASTE PIPE
I
G.
A
INLET
C
E
E
F.
D
E
B
OUTLET
H
K

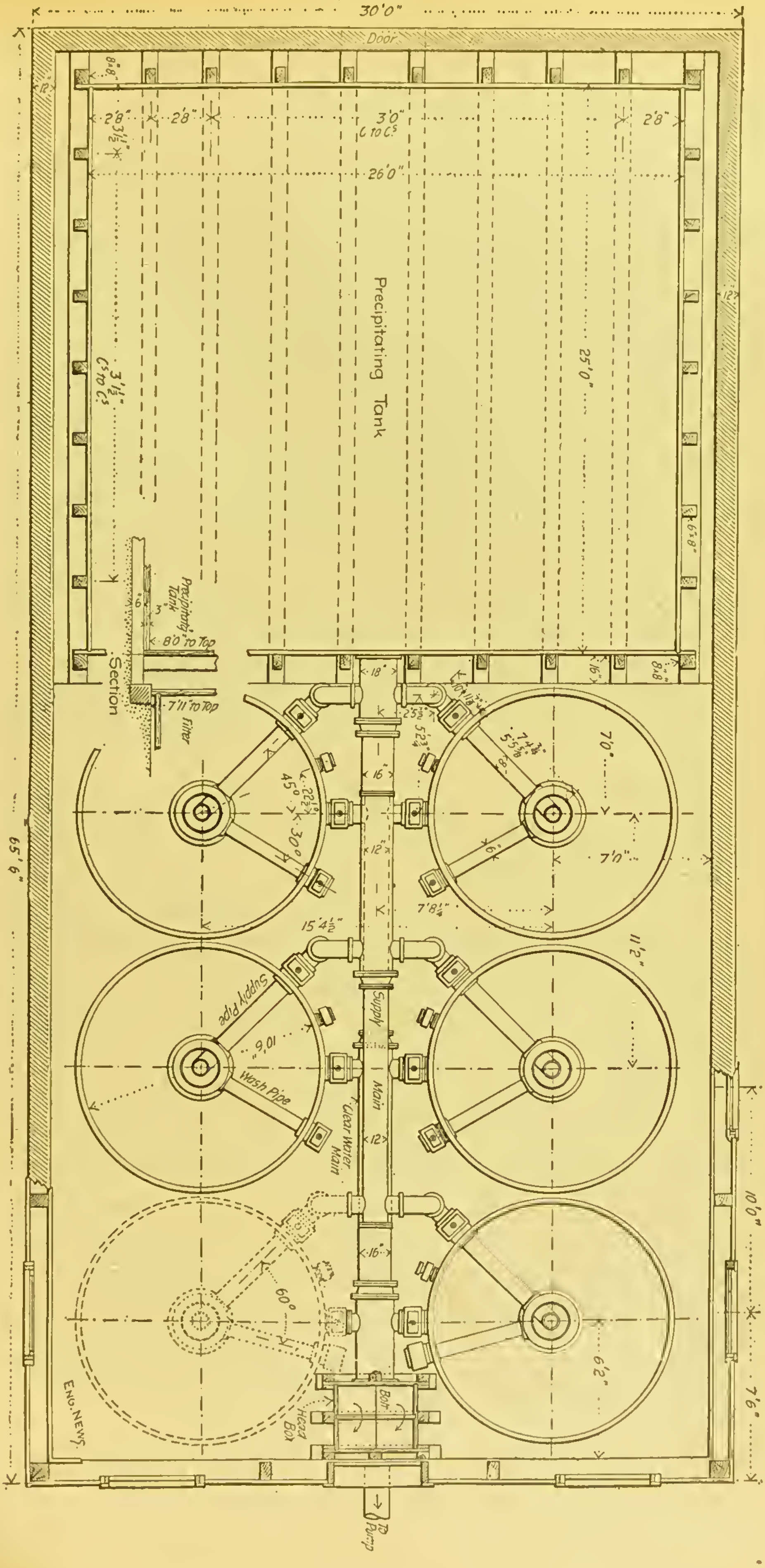

INLET

very different from one involving the building of an English filter-bed. In the latter instance the engineering problems are chiefly considered, while in the former the item of patent and proprietary rights becomes of pronounced importance.



VIEW OF OPEN FILTER-SHOWING SAND, AGITATOR, AND DRIVING MACHINERY.

Where a factor of such variable value is introduced into the calculation, an outsider can give but an indifferent estimate of cost, and it is perhaps best to merely state that any one of the several companies building these filters can, if it wish, greatly underbid the English system for plants of like capacity. Some idea, however, of the cost of this system may be obtained from the following report, by Capt. T. W. Symons, of the U. S. Engineer Corps, upon the question of



PLAN OF BATTERY OF OPEN FILTERS, WITH SETTLING-TANK.

filtering the Potomac River water for the supplying of Washington, D. C.:

"It is estimated that the total cost of everything needed to carry into effect the plan proposed will not exceed $600,000. This estimate has been arrived at from a careful consideration of everything necessary to be done, and after consultation and correspondence with many engineers and manufacturers familiar with the use of water-wheels, centrifugal pumps, etc., and particularly from the estimates furnished for the filtering-apparatus proper by the filtering company consulted. The actual final cost must depend upon the terms which can be secured from parties owning the patents on the methods and devices which it may be decided to adopt.

"It is impossible to make a close estimate of the cost of each particular part of the plan until all details are decided upon.

"It is possible that the sum mentioned may be reduced when the work comes to be done by inviting such competition as the case affords.

"The filtering company, after carefully going over the whole subject, have expressed a willingness to enter into contract to do everything required under the most stringent guarantees so that the total cost should not exceed the sum mentioned.

"It seems, therefore, perfectly safe to assume that the entire cost for everything required for the filtration of 40,000,000 gallons per day will be covered by the amount of $600,000.

"This will give sufficient water for a city of 250,000 inhabitants, allowing 160 gallons per day per capita, or for a city of 300,000 inhabitants, allowing 133 gallons per day per capita.

"This estimate includes the thorough cleansing of the re-

servoir, and making and guarding the connections with the reservoir to and from the filters and to the turbines, making the turbine-well and outlet-tunnel, putting in the turbines, shafting, gearing, belting, pulleys, pumps, ærators, coagulators, pipe-mains, hydraulic valves, and operating appliances, filters, etc.—in fact everything required, with facilities for putting in more filters and more pumping power at a small additional cost.

"The total cost per year for maintenance for the filtration of 40,000,000 gallons per day is estimated at $18,000, made up as follows:

Attendance	$3,000
Waste of filtering material	1,000
Painting and repairs	3,000
Heating, lights, lubricants, etc.	2,000
Coagulants	9,000
	$18,000

"The total yearly cost for maintenance would represent, if paid entirely by the citizens of the district, an annual expense of 8 or 9 cents per capita.

"The interest on the entire original cost at 3 per cent would under the same supposition represent a further additional expense of 8 or 9 cents per capita.

"This whole amount of maintenance and interest would make the cost per 1,000,000 gallons, on the supposition that 40,000,000 are used per day, $2.46."

As the cleaning of such filters is only a question of the occasional turning of valves, the labor item is necessarily very low. The repair bill is also small, and the filtering-material does not require frequent renewal. In very cold climates the plant must be housed and the temperature therein kept above freezing.

The areas of these filters are so small compared with

filter-beds that the delivery per square foot of sand-surface is relatively very high. For instance, the delivery of mechanical filters proposed for the city of Providence, R. I., was to have been at the rate of 128,000,000 gallons per acre daily. The following is extracted from a publication by a filter company:

SCHEDULE OF VARIOUS SIZES OF FILTERS.

Diameter.	Height.	Inlet and Outlet-pipes.	Waste Pipes.	Gallons per minute. Western States.†	Gallons per minute. Eastern States.	Max. Gallons per 24 Hours.	Test Pressure per Sq. in.	Approximate Shipping Wt. Filters.	Shipping Wt. Filtering-material.
							Lbs.	Lbs.	Lbs.
12 in.	4 ft. 6 in.	¾ in.	¾ in.	2	3	4,320	100	273	300
16 "	4 " 6 "	¾ "	¾ "	3	5	7,000	100	350	450
20 "	4 " 6 "	1 "	1 "	5	7	10 000	100	400	700
24 "	5 "	1¼ "	1¼ "	7	10	14,400	100	950	1,000
30 "	5 " 6 "	1½ "	1½ "	10	15	21,500	100	1,400	1,475
36 "	5 " 6 "	1½ "	1½ "	15	20	28,800	100	1,700	2,000
40 "	5 " 6 "	2 "	2 "	20	30	43,250	100	1,900	2,700
50 "	5 " 6 "	2½ "	2½ "	30	40	57,600	100	2,700	5,000
5 ft.	6 "	2½ "	2½ "	40	60	86,400	100	3,500	7,350
6½ "	6 " 8 "	3 "	3 "	70	100	144,000	100	4,250	13,500
8 "	8 " 6 "	4 "	4 "	100	150	216,000	100	8,000	20,000
10 "	8 " 6 "	6 "	6 "	170	250	360,000	100	12,000	31,500
*8 "	20 ft. long.	8 "	8 "	300	400	576,000	200	12,000	54,000

QUANTITY OF ALUM (IN POUNDS) REQUIRED PER MILLION GALLONS OF WATER CALCULATING FROM $\frac{1}{10}$ TO 1 GRAIN PER GALLON.

$\frac{1}{10}$ grain per gallon	14.2857
$\frac{2}{10}$ " " "	28.5714
$\frac{3}{10}$ " " "	42.8571
$\frac{4}{10}$ " " "	47.1428
$\frac{5}{10}$ " " "	71.4285
$\frac{6}{10}$ " " "	85.7142
$\frac{7}{10}$ " " "	99.9999
$\frac{8}{10}$ " " "	114.2856
$\frac{9}{10}$ " " "	128.5715
1 " " "	142.8572

* Horizontal.

† The water in Western States is generally much more turbid than in Eastern States.

These filters can be made to withstand any required pressure up to 200 pounds, at additional cost for strengthening same.

When the water is so soft as to be deficient in the necessary quantity of carbonates to decompose the alum added, the bed of ordinary filtering-sand is replaced by a mixture of such sand and granulated marble.

In illustration of the efficiency of mechanical filters, the following is extracted from the report of J. J. McKenzie upon the duty of the St. Thomas plant:

"I have completed the bacteriological examination of the samples of St. Thomas city water, and have to report the following:

Sample from well before	filtration	45,000	per c.c.
" " tap after	"	90	" "

The analyses on page 148 are extracted from a publication of a filter company.

The same company commonly issues the following guarantee:

STANDARD OF PURITY.

1st. All odor, color, and impurities in suspension shall be removed.

2d. The free ammonia in the filtered water shall not exceed 0.05 part in 1,000,000.

3d. The albuminoid ammonia shall not exceed 0.1 part in 1,000,000.

4th. No measurable amount of the coagulant, or other purifying agent used, shall be left in the filtered water.

5th. The microbes in the filtered water shall not exceed 100 colonies per cubic centimetre.

Nearly akin to the alum-charged filter-plants referred to above is a group of appliances in which some form of iron is the active agent.

"Spongy iron, obtained by the reduction of hematite ore

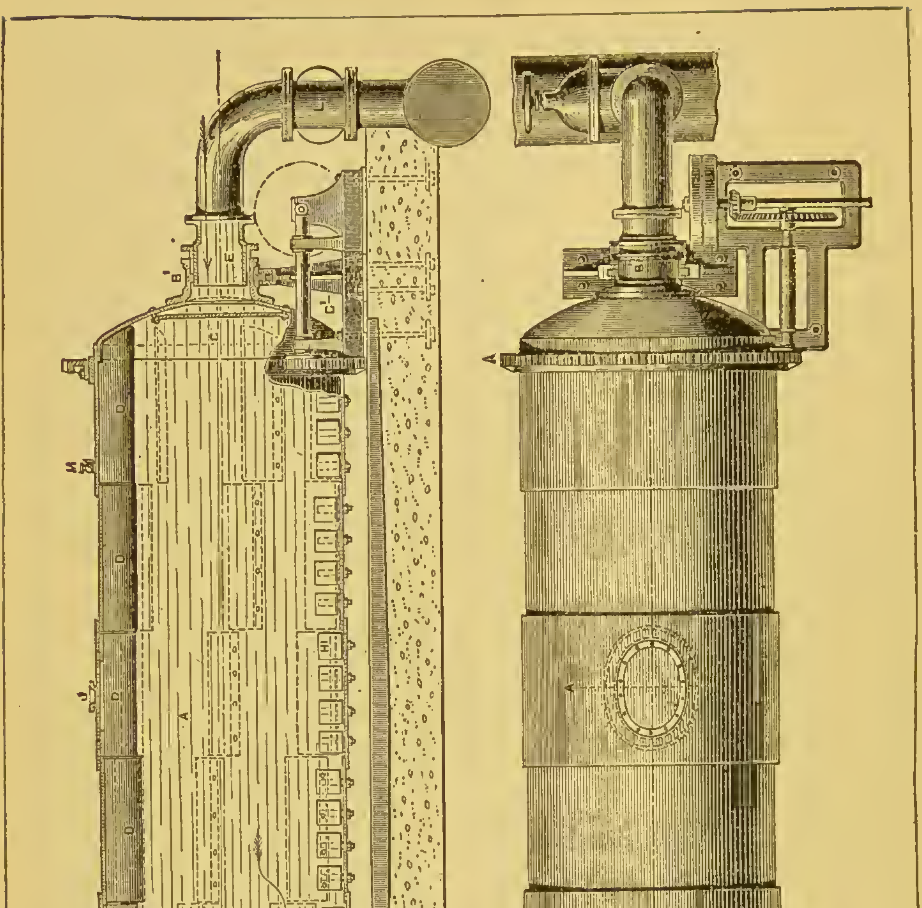
CITY WATER-SUPPLIES, BEFORE AND AFTER FILTRATION.

Locality	Bordentown, N. J.		Long Branch, N. J.		Somerville, N. J.		Little Rock, Ark.	
Source of supply	Delaware River.		Cranberry Creek.		Raritan River.		Arkansas River.	
Date	November 6, 1891.		July 8, 1892.		August 15, 1892.		December 24, 1892.	
Condition	*Before Filtration.*	*After Filtration.*	*Before Filtration.*	*After Filtration.*	*Before Filtration.*	*After Filtration.*	*Before Filtration.*	*After Filtration.*
Color	Yellow, turbid.	None.	Dark yellow.	None.	Dark brown.	Faint.	Brown, turbid.	None.
Taste	Flat, muddy.	Pleasant.	Very peaty.	None.	Earthy.	Pleasant.	Earthy.	Pleasant.
Smell	Like taste.	None.	Peaty.	None.	Earthy.	None.	Earthy.	None.
Free ammonia, in parts per 1,000,000	.05	.015	1.32	.035	.13	0.52	.015	.015
Albuminoid ammonia " " "	.21	.05	.445	.095	.49	0.15	.135	.035
Oxygen required to oxidize the organic matters " " "	1.14	.45	12.32	1.785	6.55	0.95	4.0	.83
Nitrites " " "			.025	.0015	.025			
Nitrates " " "			.876	.87	1.78	Trace.	1.13	1.13
Chlorine " " "	11.25	10.75	3.5	3.5	2.5	1.25	8.25	8.25
Total hardness " " "			22.5	22.5	72.5	72.5	60.0	55.0
Permanent hardness " " "				10.0	37.5	67.5	12.5	35.0
Temporary hardness " " "	15.	15.0	22.5	12.5	35.0	5.0	47.5	20.0
Total solids " " "	154.0	130.6	95.2	71.4	267.2	159.8	283.4	121.4
Mineral matter " " "	126.0	114.6	52.8	54.0	219.4	127.2	252.8	105.6
Organic and volatile matter " " "	28.0	16.0	42.4	17.4	47.8	32.6	30.6	15.8
Grains of alum used per gallon { maximum minimum	.28 .28	} average.	Less than 1. None.		.53 .53		2. .125	

at a temperature a little below that of fusion, thereby rendering the metal porous or spongy in form, was first made use of by Bischof, whose process was patented in England in 1871, though Dr. Medlock had secured a patent in 1857 for a process of purification based upon the use of metallic iron plates, and Spencer in 1867 introduced a material which he called magnetic carbide, in which the active agent was iron. The carbonic acid in the water, acting upon the iron in one or the other of these forms, produces a ferrous carbonate, which, by oxidation, yields hydrated ferric oxide, and this is believed to effect the oxidation of organic matter and serve as a coagulant as well, producing a flocculent precipitate, which is subsequently separated by sedimentation or filtration through sand."

"Anderson's Process" is, perhaps, the best known among the "iron methods" of purification. In this process the water is forced through purifiers consisting of iron cylinders revolving on hollow trunnions which serve for inlet and outlet-pipes. On the inner surface of the cylinders are curved ledges running lengthwise, which scoop up and shower down through the water cast-iron borings or punchings, as it flows through the cylinder, so that every portion of the water is brought into contact with the iron, which is kept constantly bright and clean by attrition. The water issuing from the purifiers is exposed to the air, by allowing it to flow through a trough, to secure the precipitation of the ferric hydrate, and by filtration through sand this precipitate is subsequently removed.

Excellent results are claimed for, and are doubtless produced by, the Anderson process, but an additional and expensive step is introduced in the item of revolving machinery, before the water is run upon the sand-filters; and it is not proved that this further outlay of capital is necessary, in view of the cheapness of some of the other and simpler meth-



"REVOLVER." ANDERSON'S PROCESS.

ods. Moreover, the process will, in some cases, signally fail, especially with brown and peaty waters, because of the iron forming a soluble compound with the organic matter present.

Mr. E. Devonshire, who is an advocate of this system of purification, places the cost of the plant as follows: The revolving machinery alone, adapted to places already possessing filters, would be $5,000 per million gallons capacity. Where an entire plant is introduced, filters and all, the expense would be $20,000 per million gallons flow. He believes that the working expenses, exclusive of interest charges, would amount to about two dollars per million gallons filtered water.

Through the courtesy of Mr. H. Regnard, of the "Compagnie Générale des Eaux," the writer was given every opportunity to examine the Anderson plant, in operation at Boulogne-sur-Seine, and also the larger one under construction at Choisy-le-Roi. A plan of the Boulogne installation is given herewith. It consists of two "revolvers" * (4 feet 6⅝ inches in diameter and 12 feet 10¼ inches in length) through which the raw Seine water is pumped. The water takes three and a half minutes to pass through the "revolver," after which it is delivered to an "ærator" consisting of inclined troughs with step-like obstructions to break the current. The greater portion of the insoluble ferric hydrate formed in the "ærator" is permitted to deposit in the "decanters" (i.e., long troughs in which the water passes alternately under and over the division-walls) and thence the water passes to the sand filter-beds.

Each drum has a capacity for purifying 2500 cubic metres (660,000 U. S. gallons) of water in twenty-four hours. Four grammes (about 62 grains) of iron are required for the treatment of one cubic metre (264 gallons) of water.

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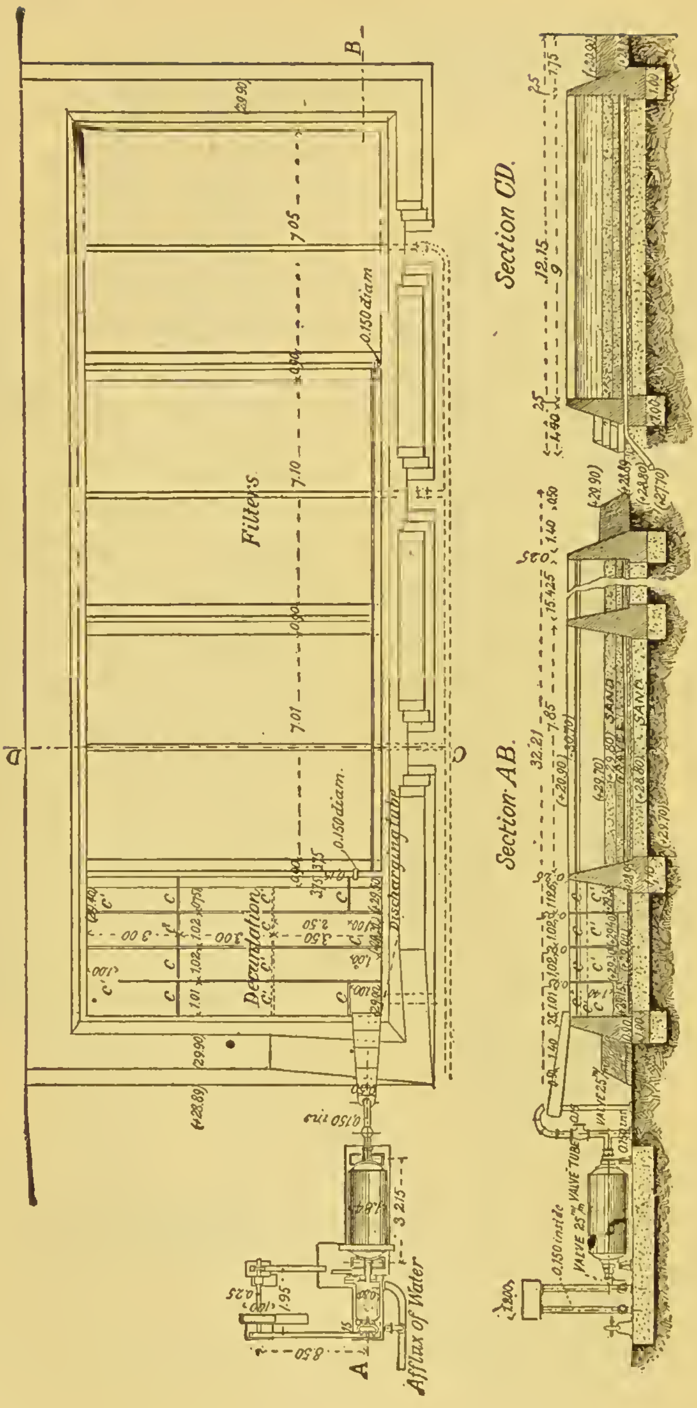
* Only one is shown in the illustration.



ANDERSON PROCESS AT BOULOGNE-SUR-SEINE.

The rate at which the water passes the filters is four vertical metres (about 13 feet) per twenty-four hours.

The "Compagnie Générale des Eaux" has put in a number of Anderson plants, and Mr. Regnard states that the average original cost, including all charges except price of land, is 30 francs ($6) per cubic metre (264 gallons) daily capacity.

The same authority states that the cost of maintenance, including all charges, together with salaries and interest on cost of plant, but excluding interest on cost of land, averages one centime ($\frac{1}{5}$ cent) per cubic metre (264 gallons) of purified water.

The present daily allowance per capita at Boulogne is twenty gallons.

The efficiency of the Boulogne plant has been carefully watched by Miquel, and his average results from thirty-one examinations made during the year are:

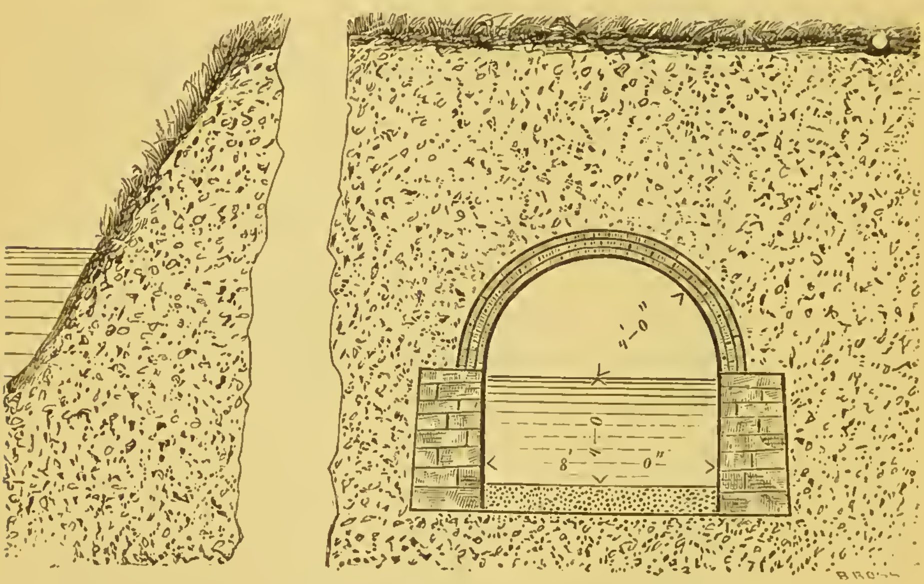
Raw water..................	333835.	bacteria per c.c.
Purified water....	1755.	" " "
Percentage of removal......	99.3	

A friend of the author's, who is an expert in water matters, writes:

"At Antwerp, while I was there, the Nethe water, after churning with iron, was ærated and then allowed to pass into a subsiding reservoir. From this it was pumped on to the ordinary English sand filter-bed, and filtered at the usual rate or a little slower. Mr. Anderson said that by scraping the iron precipitate from the surface of these filter-beds with iron chains they could somewhat prolong the period of their activity. Filtering after subsidence is essential to the iron process. As much opportunity for breaking up and deposit of the iron must be given as possible, and then the ordinary filtration is resorted to. The iron forms a soluble compound with

certain organic substances, extractive and peaty matters especially, and this must pass through the same slow process of separation by filtration as is usually resorted to when iron is not used. Indeed Easton & Anderson told me that in many cases their process could not be used at all when the extractive matters were large, and that before deciding to introduce the process they practiced with a small experimental plant. This has been my own experience. With peaty waters the soluble iron compound could be taken out by alumina, but just as good a purification could be obtained by alum alone (and precisely the same amount had to be used) as if the iron had not been employed."

In an attempt to avoid a supposed excessive expenditure of money for the construction of filtering-plants, recourse is at times had to infiltration-galleries built along the banks



FILTER-GALLERY. NICHOLS.

of a stream, or to a filter-crib sunk in the stream itself. The former devices have, in general, proved inadequate when the water is derived from the stream, and not from the water

flowing toward the stream, owing to the frequent silting up of the fine passages through which the water flows.

Filter-cribs sunk in a quickly-running stream do not easily choke with silt, owing to the clearing effects of the current; moreover, arrangements are usually provided by which a reverse current can be made to pass through the filtering-walls of the crib from within outwards.

In either of these two methods for securing a clean water-supply there is this objection, however, that the filtering-apparatus is beyond daily inspection and out of easy control, and may even be beyond repair. This was recently illustrated at Florence, Italy, where the filtering-gallery, on the banks of the Arno, was materially extended in order to add to the city's diminished supply, when, to the surprise and chagrin of all concerned, the quantity of water available was found to be even less than it was before.

The following extract is made from the specifications for a filtering-crib at Kensington, Pa., and shows the general character of such structures. The crib in question is 200 feet long, 32 feet wide, and 4 feet deep. It is designed to deliver three million gallons daily:

"The width and length of the excavation shall be such that the crib may be sunk to its proper position on a uniform and level bottom, the slopes of the excavation to be such as to permit the earth to keep in position without sliding in the bottom.

"The crib shall be built generally of 2 × 8-inch hemlock plank, of such length as to break joints. The longitudinal rows shall be 4 feet, and the transverse rows 8 feet c. to c. Blocks 2 × 8 × 8 inches shall be placed between the rows of longitudinal pieces. At each intersection or point where one plank crosses another, the plank shall be firmly spiked to the one below with 5-inch spikes having large heads. On top of the crib 2 × 4-inch hemlock shall be placed on edge and spaced

about two inches apart, to prevent the stone from falling into the crib. These 2×4s shall be secured in their place by capping-pieces, all to be firmly spiked together with spikes 9 inches long.

When the crib is ready for sinking, it shall be uniformly loaded on the top with stone sufficient in quantity to sink it. After the crib has been satisfactorily sunk to its position, stones shall be filled about the sides to prevent the gravel from working into the crib, and then the hole caused by the excavation shall be refilled to lines with selected gravel and sand."

From the sanitary standpoint, the method for purification of water which excels all others in efficiency is distillation.

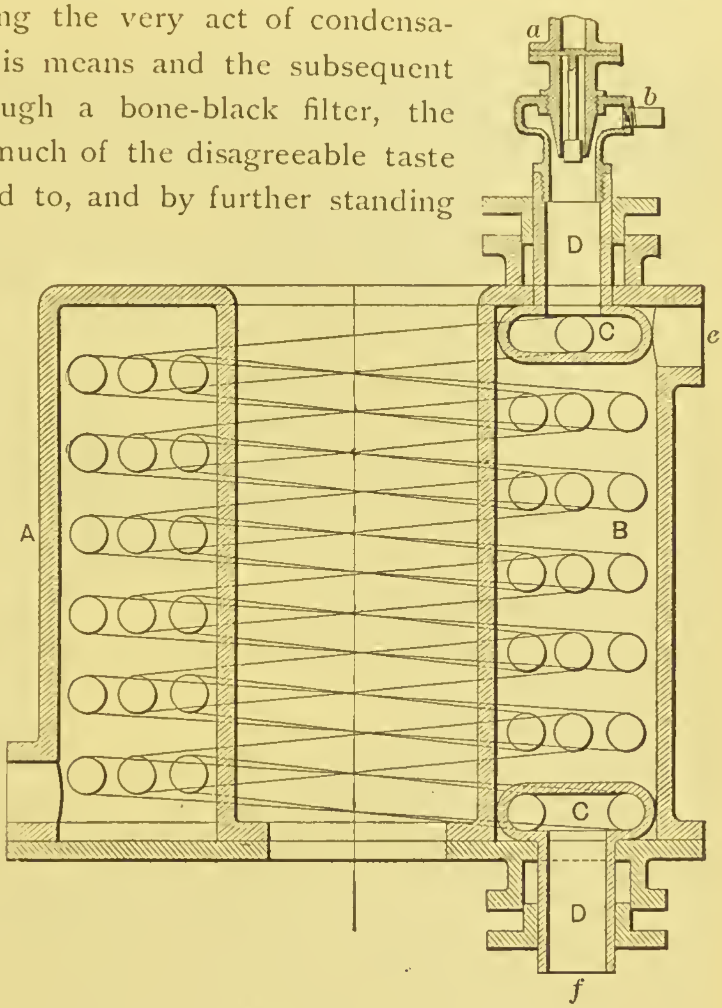
The peculiar taste of freshly distilled water is, however, disagreeable to many, and for that reason the process is not likely to become speedily popular, even if the expense be not too great. In a recent paper before the American Society of Civil Engineers, Mr. Hill advocated the use of distilled water for city supply, and basing his calculation upon one million gallons daily, delivered by small separate distribution-mains, he estimates that the total cost of the water, interest charges included, would be one-eighth of a cent per gallon, which would be at the rate of $1250 per million gallons.

Distilled water is used for drinking purposes on practically every vessel in the United States Navy, and Surgeon-General Tryon says: "It may be stated that the medical officers of the navy recognize the great value of distilled water in the improvement in health that has followed its introduction, particularly on certain foreign stations"

The apparatus used upon these vessels is one devised by Chief Engineer G. W. Baird and called by his name. An especial feature of value is the introduction of the steam into

the condenser in such a manner as to drag with it a constant and regulated current of air, thereby causing very efficient aeration during the very act of condensation. By this means and the subsequent passage through a bone-black filter, the water loses much of the disagreeable taste above referred to, and by further standing for some twelve hours the taste entirely disappears.

Plans have been recently prepared for a 100,000 - gallon plant, of the Baird type, for use in a Western town. The estimate is that $3\frac{5}{8}$ gallons of water may be distilled with one pound of coal, and that the entire expense for labor and fuel would amount to one dollar per thousand gallons delivered To this should be added something for incidentals, and also a further sum for interest on cost of plant.



BAIRDS CONDENSER.

Recently a French patent has been taken out for sterilizing water, and afterwards filtering it, by heating it to 130° C. (266° F.), under pressure. It is claimed that, inasmuch as the water, during cooling under pressure, reabsorbs

the gases driven out by the heat, the objectionable taste of distilled water is avoided.

That complete sterilization takes place at the high temperature attained there can be, of course, no question.

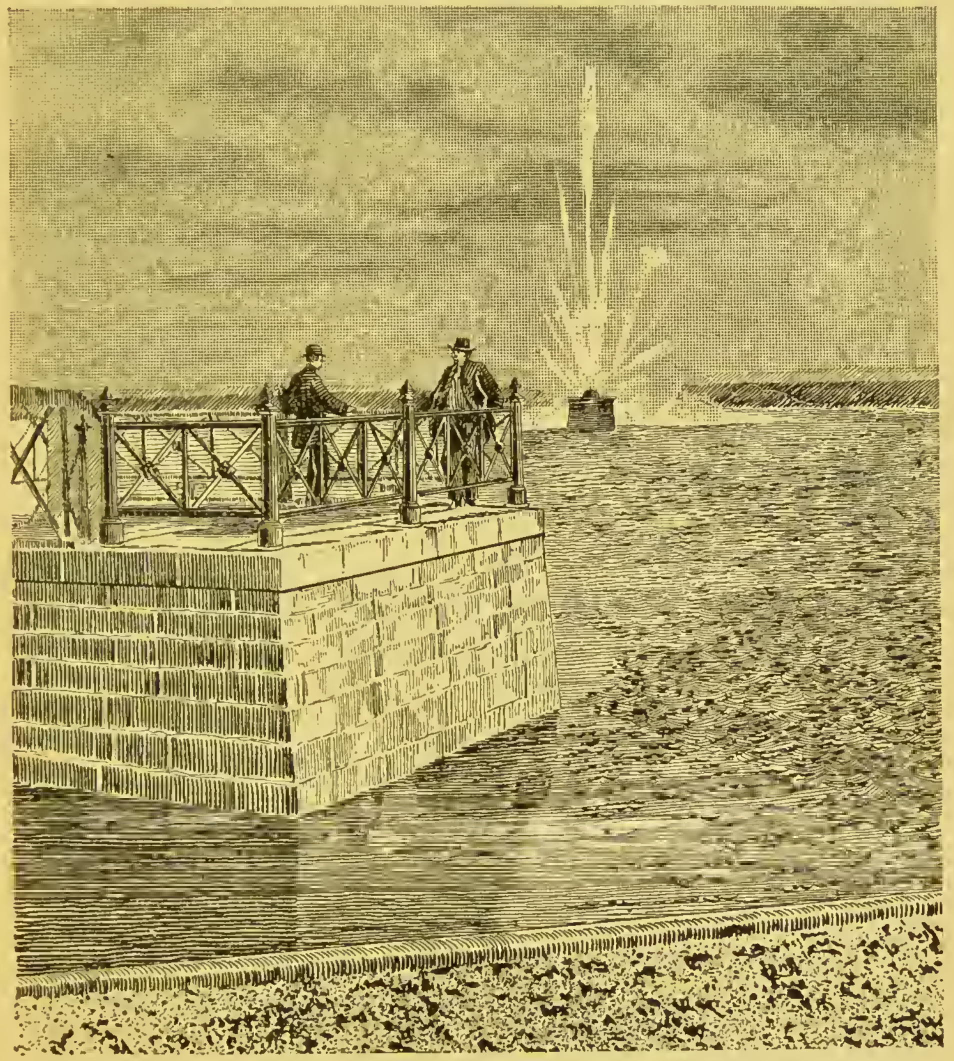
Even the spores of the now known pathogenic bacteria are rapidly destroyed by exposure to the temperature of boiling water, although those of certain non-pathogenic varieties will resist that temperature for hours. "In the practical application of steam for disinfecting purposes it must be remembered that, while steam under pressure is more effective than streaming steam, it is scarcely necessary to give it the preference, in view of the fact that all known pathogenic bacteria and their spores are quickly destroyed by the temperature of boiling water; and also that superheated steam is less effective than moist steam. When confined steam in pipes is 'superheated' it has about the same germicidal power as hot dry air at the same temperature." (Sternberg.)

Aeration of water has always held in the public mind a position of prime importance as a means of purification, and there is unquestioned benefit arising from such source, but the benefit is not to the extent that is properly believed, as will be more fully shown in another chapter.

Agitation and aeration very effectually prevent the abundant growth of algæ, with their objectionable tastes and smells; and undoubted improvement in quality of water results from the establishing of a fountain in, or otherwise blowing air into, a too-quiet reservoir.* But the expectations of those

* The aëration of the water of a large storage-reservoir by means of compressed air, to be furnished from an air-compressor on a small steamboat to be placed on the reservoir, is reported as proposed by the Butte City Waterworks Co., of Butte, Mont. The work will be carried on only during the hot weather. It is evidently intended to prevent the development of unpleasant odors or tastes in the water, due to stagnation and the growth of large numbers of minute organisms in the water.

who hope to thus easily eliminate pollution of a more serious character will not be realized.



FOUNTAIN IN RESERVOIR AT ROCHESTER, N. Y., WHEN DISCHARGING AT THE RATE OF 3,000,000 GALLONS PER TWENTY-FOUR HOURS. (FROM PHOTOGRAPH.)

So far as aeration is required to furnish oxygen wherewith the nitrifying organism can do its work, it has already been pointed out that the organism does not suffer any loss of its efficiency even though the oxygen be greatly reduced

in quantity below the normal supply. Dr. Drown found, in experimenting on sand-filtration, that there was no advantage in offering the nitrifying bacterium an excess of oxygen; just as complete oxidation was obtained with only from one to three per cent of oxygen present in the atmosphere of the filter as when the full allowance was supplied.

Aeration is of especial value in rendering highly ferruginous, deep well-waters, which are otherwise pure, fit for domestic use. By blowing air into such waters, or by even letting them stand freely exposed to the atmosphere, the iron is oxidized to insoluble ferric oxide, and may be easily removed by filtration.

A German water-supply containing 19.2 parts per million of iron is rendered fit for use by passing through a scrubber of lump coke. Thus both aeration and filtration are accomplished by one piece of apparatus. The deposit of iron on the coke is afterwards removed by washing. Dr. Drown reports a water containing 9.12 parts of iron per million. Regarding this water he says:

"When the water is exposed to the air it quickly becomes clouded, and in a short time a reddish-brown precipitate forms. This is due to the ferrous oxide in solution in the water becoming oxidized by the oxygen of the air, the ferric oxide thus formed being insoluble in water.

"When the oxidation is complete the ferric oxide may be filtered out and the filtered water is permanently clear and colorless, and has very little iron remaining in solution. The process of oxidation may be hastened by various mechanical means, such as blowing air through it or exposing the water in thin layers to the air. I have tried a great many experiments in the laboratory as to the best and most rapid means of precipitating the iron in a form that it may be successfully filtered out through a layer of sand. I have been successful in removing the iron almost completely when filtering through

rather coarse sand, at a vertical rate of 60 inches an hour or of nearly 900 gallons per square foot of filtering surface, and even a higher rate could be used successfully. The water thus treated by aeration and filtration contained only 0.02 parts per 100,000, less than half the amount contained in the present water-supply."

"In most instances water of this character, so soon as freed from its iron compounds, has been shown to be of unexceptionable quality. Frequently a mere aeration will suffice; as, for example, at Norderney, a watering-place on the North Sea." The iron-water as taken from the wells dug in the sand of the island is unfit for use. "It is aerated in a tower in which is a standpipe, and from this passes to a closed reservoir, precipitation takes place and the water becomes serviceable." *

It must not be supposed that the presence of air in solution is essential to a good water, for some of our best supplies, derived from deep wells, are entirely devoid of it.

"The sterilization of water used in bathing has been reported upon by Messrs. Foster and Nijland, chemists, of Hamburg. Their purpose was to destroy the cholera-microbes still possibly remaining in the water of the Elbe used for this purpose. They find that a 2.4 per cent solution of ordinary toilet-soap will kill the bacilli of cholera in from 10 to 15 minutes, or the ordinary duration of a bath. Salicylic and phenylic soaps are no more efficient, for to 150 litres of water they require 360 grammes of soap, which is practically too large a dose. On the contrary, a soap with 1 per cent of corrosive sublimate will kill the bacilli in one minute, with a dose of 0.12 grammes of this soap to the litre of water. To sterilize the water in 10 minutes 0.06, or even 0.03 grammes of soap per litre of water will suffice. The sublimate alone acts still better, and a solution of 1 kilo of sublimate to 30,000,000 litres of water is sufficient to kill the cholera-bacilli in 5 minutes. For an ordinary bath 5 milligrammes of the sublimate will afford every security, according to the chemists quoted."—*Engineering News.*

In these days of "applied electricity," it would be strange indeed if attempts were not made to harness up the

* Salbach in Am. Soc. C. E. xxx. 296.

"fluid" for the work of water-purification, as an addition to the many other tasks already assigned to it.

In 1888 Dr. A. R. Leeds patented a process for removing the organic impurities in water by subjecting them to the action of the nascent gases resulting from the electrolytic decomposition of a portion of the water itself. So far as the writer is aware, this process has not been pushed in general practice, and, however desirable it may be in theory, it is questionable if it be suited to the conditions likely to obtain in large plants.

Quite recently the attention of the public has been called to the "Woolf" process for water-purification as exemplified in the experiments conducted at Brewster, N. Y., upon a portion of the New York City supply.

The "Woolf" method consists in decomposing a weak solution (2 or 3 per cent) of common salt (sea-water, for instance) by means of a current from a dynamo, and then adding the electrolyzed liquid to the water to be purified in the proportion of about 10 grains per gallon of water or 1 part to 5833 by weight.

The product of the electrolysis is fancifully styled "electrozone," but the germicidal power it possesses is due to the well-known sodium hypochlorite formed during electrolysis, and not to the fancied presence of ozone. Even were ozone really in the liquid, its value as a germicide would be very doubtful in the light of recent investigations.

"Development of spores of pathogenic microbes ceases in air containing 0.1 % by volume of ozone, but as soon as the proportion of ozone falls below this figure all antiseptic action disappears. Air becomes unfit for respiration long before it is saturated with ozone to the above degree. Hence all ozone appliances recommended for disinfection depend upon an erroneous assumption." *

* *Annales de l'Inst. Pasteur.*

The sodium hypochlorite prepared by the Woolf method is not different from that made in the ordinary way, and in germicidal power it is equalled by an equivalent weight of the corresponding calcium salt, called " bleaching powder," the efficiency of each being measured by the amount of available chlorine present.*

To " disinfect " a water by either of these hypochlorites does not appeal to one as a suitable means for increasing its potability. Mr. Woolf estimates the cost of the properly electrolyzed salt-water as ten cents per thousand gallons.

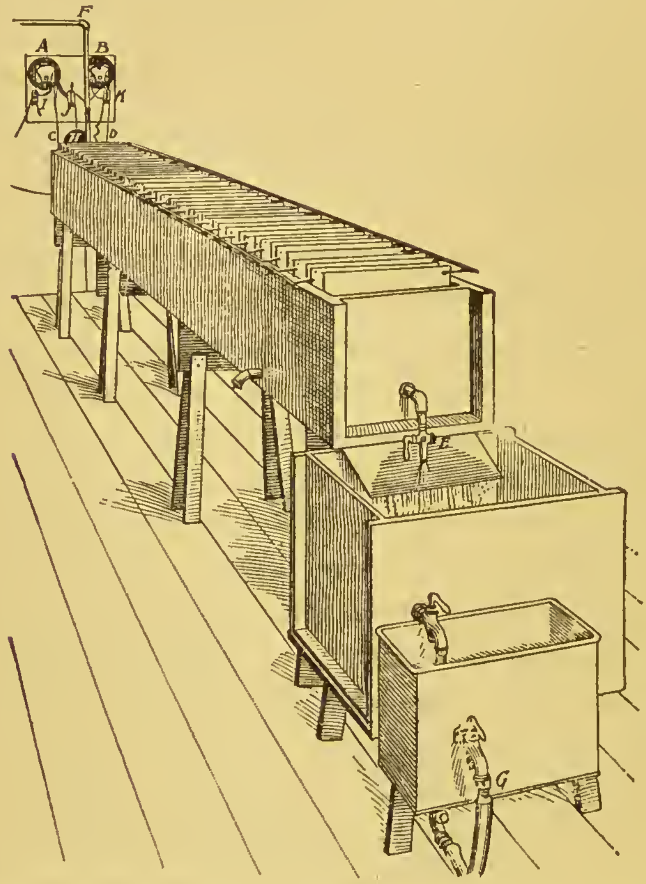
Somewhat recently another electrical purification method has appeared, which differs from the older " Webster " process only in the substitution of aluminum for iron in the anode plates. In the " Webster " process, the hydrated oxide of iron resulting from the disintegration of the anode by the passage of the electric current acted as a precipitating agent, and to this action is to be ascribed whatever value the method possesses. In the instance above referred to, where aluminum terminals are substituted for iron, the action is very similar, and purification is accomplished by the precipitating power of the hydrate of aluminum, resulting from the dissolution of the plates. Thus the method becomes really a chemical one nearly akin to the filtration systems using alum. The proprietors of the process claim exceeding low cost, and the results are apparently good. (See illustration on annexed page.)

Household filtration on the domestic scale is in very general operation, yet satisfactory results are obtained in an exceedingly small percentage of cases.

The companies manufacturing the chemical filters previously mentioned all make sizes intended for domestic use,

* The insoluble salts resulting from the use of "bleaching powder" would be a disadvantage in its use unless opportunity were afforded for settlement, and, moreover, it would render the water harder.

but the skilled labor furnished by a city employé whose sole duty it is to attend to the public plant is very rarely obtainable in the average household; consequently the filter is neglected or mismanaged, or both. In short, filtration, to



ELECTRO-ALUMINUM APPARATUS TO PURIFY 7500 GALLONS IN 24 HOURS.

Raceway 20 feet long and 18x16 inches in cross-section, with alternate aluminum and zinc plates four inches apart. The raw water enters through *F*, passes underneath each alternate plate and over the top of every other alternate plate, until it emerges through escape-pipe *E*, where it is sprayed and aerated and goes through *G* into storage-tanks.

A is an ammeter and *B* a voltmeter to measure the electric current utilized. *C* is the positive wire from the dynamo connected with each aluminum plate, and *D* is the negative wire connected with each zinc or iron plate. *H* is a ball and cock which regulates the flow of water. *I*, *J*, and *K* are the switches to make and break the electric circuit. Forty volts and twenty amperes of current are used for this apparatus.

be effectual, should be municipal. A house-filter that has come widely into use, and upon which very many people pin their faith, is the well-known "Pasteur." It is com-

monly operated under the pressure of the city mains, but may also be arranged to work without additional pressure beyond that of the atmosphere. The cut herewith given shows its simplest form, and, for those unacquainted with its use, it may be said that it consists of a cylinder of fine unglazed porcelain (called "candle" on account of its size and shape) enclosed by one of metal; and that, connection having been established between the latter and the supply-pipe, the water is forced through the pores of the porcelain to the inside of the cylinder (the so-called candle), whence it drops into the reservoir, leaving the suspended matter as a coating upon the "candle's" exterior surface.

Examination of the efficiency of the Pasteur filter has been thoroughly done by a number of investigators, with results that may be summarized as follows: Water can be completely sterilized by filtration through porcelain, but the filtration must not be continued for many days at a time. The length of time during which a sterile filtrate may be obtained will depend upon the temperature of the filter and its contents. Thus, according to Freudenreich, at a temperature of 59° to 64° F. the filtrate was sterile for from 15 to 21 days, at a temperatue of 72° F. it was sterile during 9 days, while at a temperature of 95° F. it remained sterile only 5 days.*

Water-pressure is not a factor in causing germs to pass through the porcelain, for their method of penetration is one of development rather than a transporting of initial bacteria; in other words, they "grow" through the filter. Even when

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* *Centralblatt für Bakteriologie*, XII. 240.

the pressure is nil they accomplish the passage in the usual length of time.

From a consideration of these facts the line of management for a "Pasteur" becomes plainly evident. The "candle" and its rubber packing must be removed at least once a week, thoroughly washed, and then boiled for half an hour before being reset in position.

Especial care should be taken that the rubber packing make a tight fit, as otherwise the filtrate may pass around rather than through the porcelain. The filter should not be located in too warm a place.

An arrangement, suggestive of the Pasteur, is in use on a large scale for filtering the city supply at Worms, Germany. Clean sand mixed with a little soda and silicate of lime is moulded into slabs $3\frac{1}{2}$ feet $\times$ $3\frac{1}{2}$ feet $\times$ 4 inches, and concaved on one side. These are then baked to hard biscuit-ware. Two slabs, placed with their concave sides next each other, form a closed vessel into the cavity of which the water can penetrate through the porous walls, leaving the dirt upon the outside. Series of these pairs connect with the pure-water drains. Material deposited upon the outside of these upright slabs falls to the bottom of the reservoir and is easily removed, while, as additional means of cleaning, a reverse current of live steam may be passed through the system. Although the results obtained by this system are good, they do not appear to be better than those secured by the cheaper and more widely known methods.

As showing the marked advantage to be derived from the introduction of filtered water or of water originally of good quality, the following is extracted from a report of the Minister of War of France, published in the "Journal Officiel de la République Française" for April 11, 1895, referring to typhoid fever in the French army, before and since the introduction of better water:

"To render a more accurate account it will be well to examine what has been the result in several garrisons where typhoid fever was formerly a prominent and formidable scourge. In the military district of Paris the number of cases amounted to 824 in 1888, and to 1179 in 1889; since the water of the Vanne has been substituted for Seine water the mortality from typhoid was only 299, 276, 293, 258. At the commencement of 1894 the Vanne was accidentally polluted; while typhoid fever visited all the surrounding districts, the garrison itself had 436 typhoid cases, of which 310 were in the months of February, March and April. During the first two months of this year they had only 8 cases.

"At Beauvais, during three consecutive years, there were 20, 96, and 72 cases of typhoid fever. The use of spring-water since 1891 reduced the number of cases to 2, 9, 8, and 5 for each of the following years.

"The serious epidemic of Auxerre in 1892 affected 129 men; filters were put up, and there was not a single case of typhoid in 1893, and but 1 in 1894.

"At Melun the cases of typhoid have, since the setting up of the filter, decreased from 122 in 1889 to 15, 6, 2, 7, and 7.

"In the garrison of Cherbourg there have been 110 and 119 cases observed in 1888 and 1889; filters were put up in 1890, and the cases of typhoid fever fell successively to 21, 8, 11, 3, and 3.

"We must not forget to speak of the garrison at Dinan, which, having had in three years 835 typhoid cases, has had annually, since filtration of its drinking-water, but 1, 2, 3, and 1.

"Absolutely identical results, due to the same cause, have been noticed from year to year at Montpelier, where the number of cases of typhoid fever fell from 391 to 49,

then to 14. At Perpignan, where, after having been 131 and 197, it is now but 18. It was the same at Blois, Vendome, Lure, Auxonne, Vitre, Tulle, Clermont-Ferrand, Chambery, Privas, Avignon, Toulon, Nice, Tarascon, Beziers, Lunel, etc., etc. In the fifteenth corps there were 1018, now there are only 337; in the twelfth corps, 616 is now reduced to 68. In the garrison of Angouleme, in particular, it fell from 326 to 25; finally, in the eighteenth corps, it reached, in 1888, 292 cases, and is now only 38.

"A progressive and constant decrease justifies the certainty of the effect of the substitution of spring and filtered water for water which the army commonly used in their barracks."

For the whole French army, the statistics are:

	Cases.	Deaths.
1886	7771	964
1887	6130	763
1888	4884	801
1889	4274	701
1890	3901	607
1891	3603	561
1892	4820	739
1893	3314	550
1894	3060	530

Many types of household-filters are of such character as to preclude the possibility of sterilization, and some of them it is even impossible to clean without the entire renewal of the filtering-material. Such defects are necessarily fatal to proper filtration. The stone-filters one sees at times, where the water is caused to drip through fine-grained sand-rock, or similar material, act as mere strainers and are absolutely unreliable. Currier demonstrated that sponge filters, after use for even a single day, furnished a filtrate containing five

hundred times as many germs as the unfiltered water. The author has seen household-filters of many types so seriously contaminated that a water could not but be rendered worse by passage through them, and yet such appliances were in full use, and greatly trusted on account of the apparent clearness of the water drawn from them.

The unsatisfactory results observed where really good household-filters are in use are unfortunately very apparent, but the fault is more commonly with the attendant than with the filter. The common belief is that a filter, once established, is good for all time, and the author could tell tales of what he has seen, in otherwise well-organized establishments, that would stagger belief.

Much stress is often laid upon the purifying effects of animal charcoal, and the great quantity of occluded oxygen the fresh charcoal contains fully justifies for a time the high praise given it, but such material is nearly impossible to cleanse, and it has been repeatedly shown that a more objectionable appliance could scarcely be found, from a sanitary point of view, than a neglected charcoal filter. For instance, Frankland finds that in the case of such a filter having been in use a month, the filtrate contained 6958 germs per cubic centimetre, as against 1281 per cubic centimetre in the unfiltered water.*

During the typhoid outbreak which occurred at Providence, R. I., some years ago, a number of private house filters were examined by Dr. Prudden, and three of them were found to contain the typhoid bacillus.†

How very unsafe filters of animal charcoal are, particularly if they be old, may be quickly seen from the following record, made by Percy Frankland, of water passed through a filter composed of six inches of such charcoal, in a fine state of division:

* *Chemical News*, LII. 27. † *N. Y. Med. Jour.* L. 14.

Period.	Organism per Cubic Centimetre.	
	Unfiltered Water.	Filtered Water.
Initial................	Very numerous.	none
After 12 days.........	2800	none
After 1 month........	1280	7000

The use of the old filter is thus seen to materially damage the water.

Finally, there is no way of purifying a polluted water, as some people would have us do, by throwing a remedy into the well or cistern; neither is there any value in coloring the water with wine before drinking it, a custom so widely observed in Europe.

In 1873 Crookes proposed the following mixture for addition to the highly impure waters of the Gold Coast before they were used by the troops during the Ashantee war:

Calcium permanganate................	1 part
Aluminum sulphate...................	10 parts
Fine clay............	30 "

The mixture does not act quickly enough for use by soldiers on the march. It was found that moving organisms survived for more than a day in an intensely red solution of permanganate.*

* *Chemical News*, LXXI. 43.

CHAPTER IV.

NATURAL PURIFICATION OF WATER.

NATURE disposes in sundry ways of the various elements of impurity added to water, but by far the most efficient of these is the interesting process termed "nitrification." This is a change of state best established by infiltration through soil, a few feet of such passage being capable of doing more to restore a water to its original purity than many miles of flow in an open channel.

Nitrification is accomplished by a bacillus, whose function is to tear asunder the objectionable nitrogenous organic materials and convert them into harmless inorganic forms, which are at the same time valuable as plant-food.

The conditions under which this little germ can thrive must be met, otherwise its oxidizing action will quickly diminish, or even entirely cease. Darkness is favorable, and strong light stops all action. A supply of free oxygen must be at hand, but, as has been pointed out by Drown, a small fraction of the amount normally present in the atmosphere will quite suffice for complete nitrification. A base, preferably calcium carbonate, is necessary to fix the nitric acid formed, and the presence of some phosphate is also required.

The action of the organism is mainly confined to the upper layers of the soil, i.e., to those portions subject to cultivation, and it rarely occurs below a depth of six feet.*

* This diminution in number occurs in the case of other germs as well, as is shown by Koch. Beumer found in unclean earth forty-four million bacteria per cubic centremetre at a depth of three metres, and only five millions at a depth of six metres.

The most favorable temperature for its development is 98° F.

One feature of special interest is that the nitrifying organism does not thrive in presence of a great excess of organic matter. It cannot be successfully cultivated in either bouillon or strong sewage. Furthermore, it is noticed that where nitrification is once thoroughly established, other germs tend to die out, probably on account of lack of food-supply.

The great importance of this purifying process of nitrification will be better appreciated when we come to consider the question of ground-water, for it is at once apparent that our wells must receive large contributions from drainage material poured into and upon the soil. One thing must be ever borne in mind when depending upon the purifying action of soil, namely, that its power must not be overtaxed by excessive doses of sewage-material, and that its filtering action must always be permitted to be intermittent, so that a proper supply of oxygen may always be present. The importance of aerating the filtering-soil between the successive applications of sewage has been abundantly shown by the Massachusetts Board of Health, and the advantages of so doing are demonstrated on the large scale at the sewage farm of Asnières, near Paris.*

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* The sewers of Paris, aggregating over 750 miles in length, constitute one of the sights of the city. They may be inspected without charge on the first and third Wednesdays of each month in summer by writing for a permit to the Préfect de la Seine. Descent is commonly made near the Madeleine by a substantial stairway of stone, and the boats awaiting the party at the foot of the steps are fully as large and quite as comfortable as Venetian gondolas.

The great sewer, which is tunnel-like in dimensions, being 16 feet high and 18 feet broad, is, on occasion of a visit, lighted with lamps alternately red and blue, and as these stretch away into the distance the effect is decidedly striking.

Under ordinary circumstances the sewage confines itself to the central channel-way, but upon occasion rises above the sidewalks on either hand. The central channel I should estimate as 10 feet wide and 4 feet deep, with a curved bottom and a walk on either side. The boats, with their loads of visitors, are pulled by ropes in the hands of attendants who walk along the sidewalks. On either side of the sewer may be seen the large mains carrying the city water-supply and also the telegraph cables.

Sewage for the purpose of this irrigation at Asnières is conducted throughout the irrigated district in open conduits of earth about 2 feet wide and 3 feet above the surface of the surrounding country. Small side-gates at intervals admit the sewage to the furrows between the rows of growing plants, such gates being opened and the furrows filled whenever, in the judgment of the attendant, the vegetation can appropriate the sewage.

The face of the land is all divided into small sections, in places less than an acre in area, and each such division is flooded independently. What is very important to note is that the filtration of the sewage through the soil is entirely intermittent in character, and that nitrification is given abundant opportunity for full development.

Any surface-clogging of the ground is avoided by suitable use of the spade. So far as the quantity and quality of the crops raised are concerned, they appear to be very near perfection.

Flowing at the base of the gentle slope of the irrigation district is a sparkling stream, several feet wide, consisting of the effluent or underdrainage of the sewage farm. It is full of trout and has the appearance and taste of ordinary drinking-water. The distance of this stream from the nearest

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The *collecteur-général*, or main collecting sewer, after receiving the contents of the tributaries starts from the Place de la Concorde and descends to Asnières, nearly 3½ miles distant.

This great sewer carries about 350,000 cubic feet of sewage per hour (63,000,000 gallons per day), but is capable of passing many times that quantity.

The sewage from that portion of the city lying on the left bank of the Seine is piped under the river, passes below the Avenue Marceau and the Place de l'Etoile at a depth of about 100 feet from the surface of the ground, and joins the *collecteur-général* not far from the point where the latter empties its contents into the Seine.

Before the mouth of the main sewer is reached, a portion of its contents is deflected and used for irrigation upon the farm and "model garden" at Asnières.

irrigation point is about 100 feet. The average analysis fore the year 1889 of the sewage admitted to the farm and of the water of the effluent stream mentioned above, was as follows:

	Parts per Million. Sewage.	Stream.
Chlorine	78.0	71.0
Organic matter	45.0	1.4
Nitrogen as nitrates	6.8	23.1

In this connection it may be incidentally stated that the average composition of city sewage in the United States, as given by Mills, is:

Water	998 parts
Mineral matter	1 part
Organic matter	1 "
	1000 parts

Owing to smaller volume of water-supply, per capita, European sewage may be taken as about twice as strong as the above.*

The conclusions reached by the Massachusetts Board of Health are as follows:

"The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purification for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage dis-

* Because of great waste of water, Troy sewage is still weaker, as is shown elsewhere.

tributed over the surface of sand-particles, in contact with an excess of air for a sufficient time, is sure to give a well oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts. Both of these qualities depend upon the physical characteristics of the material. The ability of a sand to purify sewage, and also the treatment required for the best results, bear a very close relation to its mechanical composition."

We have seen that nature makes abundant provision for the removal of pollution from water that is poured upon the soil; let us now inquire as to the efficiency of those means, so highly thought of by the people at large, and supplied wherever the water passes over riffles and falls, namely, agitation and aeration. Does direct oxidation take place, and, if so, to what extent? With a view of obtaining light upon this question, an extended series of experiments was undertaken in the writer's laboratory in the following manner:

Varying amounts of sewage were placed in bottles, water added until the dilution reached 3000 c.c., the mixture was then thoroughly stirred, and 1500 c.c. were taken out and analyzed. The bottle containing the remaining 1500 c.c. was then securely fastened to the connecting-rod of a horizontal steam-engine of 10-inch stroke, running at a speed of 75 revolutions per minute, so that in an hour the water was subjected to 9000 violent concussions and traveled 1.25 miles.

The lengths of time during which the waters were thus lashed into spray varied from 18 to 60 hours. The mean temperature of the water during the shaking was 30° C.

An analysis of each water after shaking showed that the amount of oxidation which took place during the agitation

of the water was very trifling, a finding entirely in accordance with Prof. Leed's observations of the water of the Niagara River before and after passing Niagara Falls. Direct oxidation does not seem to be a factor of any considerable importance in the purification of polluted water.

In just this connection, and as a result of his own investigations, Frankland says:

"I should say that it is simply impossible that the oxidizing power acting on sewage running in mixture with water over a distance of any length is sufficient to remove its noxious quality. I presume that the sewage could only come in contact with oxygen from the oxygen contained in the water and also from the oxygen on the surface of the water, and we are aware that ordinary oxygen does not exercise any rapid oxidizing power on organic matter. We know that to destroy organic matter the most powerful oxidizing agents are required. We must boil it with nitric and chloric acid and the most perfect chemical reagents. To think to get rid of organic matter by exposure to the air for a short time is absurd."

Of course what has been said refers to direct oxidation by atmospheric oxygen and does not cover the possibility of improvement by destruction of objectionable microbes; but, bearing in mind the known powers of resistance of the various bacteria, it is difficult to conceive of any appreciable diminution in their numbers resulting from a short-time exposure of the water in the form of spray.

Neither is it easy to see that the labors of the nitrifying bacillus can be materially aided by the momentary passage of a fall, when we remember the small percentage of dissolved oxygen required for the fulfilment of its task.

That the said nitrifying bacillus can, under any circumstances, accomplish in a water the quantity of work expected of it in a soil is, of course, not to be hoped for.

It must not be assumed, however, that the old and firmly planted belief of the people is entirely false, and that aeration is without any value whatever. As has been said (page 158), keeping a water well saturated with atmospheric oxygen, either by spraying it in form of a fountain, as at Rochester and elsewhere, or by pumping air into it, either in the reservoir or directly into the force-main, unquestionably renders less likely the growth of algæ, with their accompanying odors and tastes, and also removes, by direct displacement, any foul gases already in solution.

It is therefore undoubted wisdom to encourage the existing tendency to aerate public waters, but the true action of such aeration must be always kept in mind, to the exclusion of false and exaggerated notions of its value.

Sedimentation is another purifying process upon which wide dependence is very justly placed. Its consideration would properly come under a discussion of lake and reservoir-waters, but a word should be said here with reference to what may be expected of it in the cases of streams and rivers.

With a view of determining to what extent sedimentation can be depended upon for the purification of streams, the following inquiry was undertaken.

Upon four different occasions (covering various conditions of medium, high water, and flood) samples were analyzed from that section of the Hudson River extending between Troy and Albany. The stations at which samples were taken are situated over one mile apart, beginning at State Street, Troy, and ending at the Albany intake, five miles below. Two samples were taken at each station during ebb-tide and in mid-channel; one two feet from the surface and the other, as near as could be judged, two feet from the bottom.

The first set of samples was taken on April 26, the river being at the time two feet above normal. The appearance of the water on that date was clear, and, owing to warm weather during the early part of April, all snow-water was probably absent from the river.

The second set of samples was taken on May 12, the water being 4.2 feet above normal. The State canals had already been opened and numerous tugs and steamboats agitated the water; it had rained on the previous day. The water appeared clear.

The third set of samples was taken on May 23, the water being very turbid and reading 11.5 feet above normal.

On May 31 the fourth and last set of samples was collected. The water was still high, reading 9.5 feet above normal, and was very turbid.

All samples were analyzed as soon as obtained, and from the examination of the analytical results the conclusion seems to be justified that water containing a considerable amount of suspended matter capable of settling is to a certain degree purified, in accordance with the well-known laboratory observation that solid material, no matter how minute, on settling will often drag with it and precipitate more or less other materials, even though the latter be in solution.

As expected, total solids were higher during flood; at the same time the analysis showed the water in a poorer condition than when the river was low, even though the dilution was much greater. This is to be accounted for by the fact that during high water a great increase of surface washing occurs which always carries greatly increased impurities to the main stream.

The examination of the total solids showed sedimentation at all stages of the river, the average being nearly constant throughout the entire distance.

Such sedimentation is, however, decidedly small. An idea of the amount deposited may be obtained from the fact that average differences between the upper and the lower samples at station C* is 3.47 per cent of the total solids in the upper sample. The results for "required oxygen" disclosed the fact that sedimentation takes place, though the percentage of improvement appeared much smaller than that indicated by the total solids. The fact that free ammonia increased showed a step toward oxidation.

During flood, albuminoid ammonia increased, owing to more fresh organic matter coming into the stream and decomposing from the first to the second stage of oxidation.

In order to get some idea of general purification, the following is a tabulated statement showing the amount of each ingredient in the upper sample at Albany as compared with the corresponding one at Troy. The calculations are based on the average† results in parts per million.

	Troy.	Albany.
Free ammonia	0.0418	0.6000
Albuminoid ammonia	0.1667	0.1550
Required oxygen	6.5310	5.8750
Nitrates	0.4636	0.4872
Total solids	94.2500	116.0000

Nitrites were found in traces only. The results for "required oxygen" showed some improvement, but the differences were two small to be noteworthy. Nitrates had a tendency to run high in lower samples, giving signs of oxidation, but such oxidation appeared to have been exceedingly slow, judging from the results obtained.

A review of the evidence given leads to the belief that

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* End of the second mile.

† The complete analyses for each station are published in *J. Anal. and Applied Chem.* VI. 505.

sedimentation is a source of river purification in streams such as the Hudson, although not nearly so pronounced a one as has been heretofore held.

So far as the removal of bacteria from river-water by sedimentation is concerned, it must be remembered that, their specific gravities being but slightly greater than unity, they sink but slowly in still water, and of necessity still less rapidly in that which is moving. That specific germs do not completely subside during long distances of flow may be inferred from the typhoid statistics already given.

The old notion that water completely purifies itself by freezing has by no means died out, and even after Prudden's able report on the contaminated condition of much of the public ice-supply, we find educated people collecting ice from sources so polluted as to be beyond question unfit to furnish drinking-water. A somewhat aggravated case of this kind having presented itself, the following experiments were undertaken to outline the relation existing between an ice and the water from which it is frozen. The materials employed for experiment were mixed with ordinary tap-water. The given weights are in grammes per 100 c.c. of water. (See table on next page.)

Dilute sulphuric acid was prepared of a strength = .3280 gms. H_2SO_4 per litre. The ice from same when melted retained H_2SO_4 corresponding to .0390 gms. per litre. Ice retained 11.89 per cent of the H_2SO_4 in the water.

From the foregoing it will be observed that organic impurity is more liable than mineral matter to pass into ice, and, inasmuch as the organic impurity is the more objectionable of the two, the distinction is important. It will be noticed that the waters containing sewage and urine formed ices of the greatest organic percentages.

Of the fifteen waters containing organic impurity, the

	Total residue from 100 cc.	Loss on Ignition. Volatile and Organic Matter.	Inorganic Residue.	Per Cent of the Mineral Matter Originally in the Water yet Remaining in the Ice.	Per Cent of Organic and Volatile Matter of the Water yet Remaining in the Ice.
100 c.c. urine diluted to 10 litres	.0285	.0070	.0215		
Ice from same	.0023	.0022	.0001	0.46	31.43
500 c.c. urine diluted to 10 litres	.1380	.0469	.0911		
Ice from same	.0389	.0213	.0176	19.32	45.41
10 c.c. urine in 10 litres of water	.0112	.0047	.0065		
Ice from same	.0040	.0018	.0022	33.84	38.21
100 c.c. glycerine diluted to 10 litres	.7951	.7911	.0040		
Ice from same	.1012	.1005	.0007	17.50	12.70
50 gms. sugar dissolved in 10 litres water	.4932	.4860	.0072		
Ice from same	.1373	.1360	.0013	18.05	27.98
50 gms. NaCl in 10 litres water *	.5013	0	.5013		
Ice from same	.1449	0	.1449	28.9	
10 litres of water tinted with indigo	.0399	.0336	.0063		
Ice from same	.0027	.0027			8.03
10 litres H_2O, with a little egg-albumen, i.e., $\frac{1}{2}$ of that in one egg	.0163	.0119	.0044		
Ice from same	.0038	.0031	.0007	15.91	26.05
10 gms. Na_2CO_3 in 10 litres of water	.0907	.0038	.0869		
Ice from same	.0180	.0025	.0155	17.83	65.78
10 gms. sugar in 10 litres of water	.1045	.0996	.0049		
Ice from same	.0118	.0100	.0018	36.73	10.04
10 gms. oxalic acid in 10 litres of water	.0129	.0067	.0062		
Ice from same	.0037	.0022	.0015	24.19	32.82
10 gms. glycerin in 10 litres of water	.0187	.0140	.0047		
Ice from same	.0028	.0010	.0018	38.30	7.14
Troy City supply	.0092	.0035	.0057		
Ice from same	.0010	.0010	trace	0	28.5
Very hard spring-water	.0540	0	.0540		
Ice from same	.0045	0	.0045	8.3	
Water from Erie Canal where public ice-supply is taken	.0112	.0033	.0079		
Ice from above locality used for public supply	.0067	.0025	.0042	53.2	75.7

* SUCCESSIVE CROPS OF ICE-CRYSTALS FROM SEA-WATER EXPOSED TO — 50° C. IN A BEAKER AND CONSTANTLY STIRRED.

			Volume.
Original sea-water	contained	1.979 per cent chlorine	1529 c.c.
1° crop ice	contained	1.525 per cent chlorine	165 c.c.
2° " "	"	1.624 " " "	410 "
3° " "	"	1.819 " " "	390 "
4° " "	"	2.003 " " "	354 "
Final mortar liquor	"	2.987 " " "	210 "
			1549 c.c.

("Observations on Arctic Sea-water and Ice," by E. L. Moss., Proc. Roy. Soc. XXVII. 544.)

percentages of such impurity retained by the ice varied from 7.14 per cent to 75.75 per cent, with an average of 34.3 per cent, while of the eighteen waters holding mineral impurity, the ices formed therefrom retained from a trace to 53.20 per cent of such impurity, with an average of 21.2 per cent.

The entire inadequacy of cold to purify water from bacterial pollution is more fully referred to upon another page.

It remains to say a word concerning the purifying action of sunlight supplementary to what has been already given on page 66.

Very exhaustive investigations by Prof. H. Marshall Ward show light to have great germicidal action and that "the rays which kill the bacteria are the blue and violet ones. The infra-red, red, orange, yellow, and green are without effect, and the effect weakens as we pass beyond the visible violet."

"This explains why these organisms are destroyed so much more rapidly by the light of the summer sun than in winter; why a clear blue sky is so much more effective than a hazy one, and why direct sunlight acts so much more quickly than reflected or diffused daylight." *

Investigations upon this very interesting topic are of recent date, and are, as yet, in an uncompleted form, but enough has been done to show the marked toxic effect of sunlight upon bacterial life and its consequent aid to the effort of the sanitarian. For full and detailed information upon the subject, the reader is referred to the recent work of Percy Frankland.† Stated roughly, sunlight is fatal to bacteria, sooner or later, the intensity of the action depending upon the kind of germ and the brightness of the light.

Buchner gives a very interesting and graphic illustration

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* *Chemical News*, LXX. 243. † "Micro-organisms in Water."

of the action of light, using the typhoid bacillus for the demonstration,* and the value of such experiments is very far-reaching, and suggestions of great sanitary importance naturally follow.

Of more direct bearing upon our present consideration, however, are the investigations Buchner instituted concerning the action of sunlight upon the typhoid germ at different depths of water. He found that plates of inoculated jelly were sterilized by exposure during 4½ hours at a depth of 5 feet 3 inches in the waters of Starnberger Lake, near Munich; while similar plates exposed during the same period at a depth of 10 feet 2 inches barely exhibited any diminution of virility whatever.

The bearing this point has upon the influence of sunlight upon the self-purification of streams is at once apparent; but it must not be forgotten that a comparatively thin layer of water will cut off an immense deal of the germicidal power of sunlight, and we must consequently restrain our tendency to enlarge and exaggerate the beneficial action.

In this connection it is interesting to study the antiseptic action (recorded by Procacci) of mid-day sunlight, in June, upon bacterial life contained in drain-water forty inches deep. The light was passed through the water vertically, side-light being excluded, and the time of exposure was three hours. Comparison tests, kept in darkness, were also made. The results were as follows per cubic centimetre:

	Before Exposure.	Sunshine.	Darkness.
Surface.............	2100	9	3103
Centre...............	2103	10	3021
Bottom.............	2140	2115	3463

The sterilizing action of light upon the upper portion of the water is thus seen to have been very marked.

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* "Einfluss des Lichtes auf Bakterien."—*Centralblatt f. Bakteriologie*, XI. 781.

Self-purification of Streams.

Pettenkoffer expresses the opinion * that "ordinary sewage may be, without hesitation, turned into any river or brook whose volume is fifteen times the volume of the sewage, and whose velocity is not less than that of the stream of sewage. Under these circumstances the necessary dilution and self-purification take place after a short flow."

If this were only true, the vexed question of sewage disposal would be very largely disposed of, and enormous sums of money now expended in such disposal would be saved. That it is very far from being safe practice is evidenced by such statistics as have already been quoted showing the serious pollution of large rivers by small streams of sewage inflow. It has been shown (page 30) that twenty-six miles of flow were not enough to protect Albany from the contaminated sewage of Schenectady, even when the rivers in question were so large as the Mohawk and Hudson, and with the high "Cohoes" falls on the route.

Prof. Sedgwick gives an instance of similar carriage by the Merrimac River:

"In the eight months preceding August, 1892, two cases of typhoid were reported in Newburyport, in the subsequent

TYPHOID INFECTION CARRIED TWENTY-FIVE MILES BY RIVER.

	Cases Reported.			Deaths.		
	Lowell.	Lawrence.	Newb'port.	Lowell.	Lawrence.	Newb'port.
November, 1892	19	14	0	3	4	0
December, 1892	70	32	4	10	9	1
January, 1893..	38	72	28	10	3	3
February, 1893.	14	23	9	7	12	0
March, 1893....	....	....	....	4	4	1

—*From Mass. Reports,* 1892.

* Fischer, "Das Wasser," 268.

five there were ten; twenty-eight cases in January, 1893, were thus very unusual. These cases appeared in the same month, but earlier than the increase in Lawrence; they were therefore due to infection from Lowell, more than twenty-five miles distant. The people had warning of the danger from Lawrence."

In their sixth report (page 138) the Rivers Pollution Commissioners of Great Britain say: "We are led to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxidized. It will be safe to infer, however, that there is no river in the United Kingdom long enough to effect destruction of sewage by oxidation."

The inference contained in this old report is not entirely in accord with modern experience, for it will be shown that purifying changes take place with greater rapidity when sewage is present in water in large rather than in small quantity; but the conclusion of the commissioners, that complete purification is impossible within reasonable length of flow, is certainly the accepted doctrine of to-day. We no longer look entirely to the chemical examination for our information, and we recognize other elements of harmfulness than merely dead organic waste material, and other means of oxidation than direct atmospheric action; but we believe, as they did, that self-purification of streams is a process not to be implicitly relied on, and that simple dilution enters largely into the safety-factor of those who drink water from a polluted river.

It must not be thought that all self-purification is absolutely denied; on the contrary, much is unquestionably accomplished. Thus Prausnitz found the following changes in

number of bacteria per cubic centimetre in the water of the Isar River at Munich, where the velocity of current is about three miles per hour:

Above Munich	531
Ten miles below Munich	9111
Seventeen " "	4796
Twenty-six " "	2378

From the chemical standpoint much has been said and written upon the ability of sewage-laden streams to purify themselves, and authorities of great weight are to be found on that side. Some time since a series of analyses were made, by Dr. Long of Chicago, of the dilute sewage contained in the Illinois and Michigan Canal. It is to be noted that this canal receives its supply of water (or rather dilute sewage) at Bridgeport, where the pumps deliver to it the filthy water of the Chicago River, contaminated with a great portion of the sewage of Chicago. From Bridgeport the water "flows along the level to Lockport, twenty-nine miles below, requiring about a day for its passage." It receives no dilution on the way and is frequently agitated by passing boats. "After passing Lockport the water descends to Joliet through four locks, and falls over a dam seven feet in height to point of collection. There is a fall of 58.2 feet in a distance of four miles, and no dilution takes place on the way." The experiments with this canal-water have been both numerous and thorough, and judging from the mean results there is good ground for the statement that very considerable self-purification takes place during the flow of thirty-three miles.

I have long been of the opinion, however, that what may be true for dilute sewage does not hold good as we approach the limit of potable water.

In other words, so far as purification of a water by the

natural processes of oxidation is concerned, I believe that the rate of such purification varies directly as the amount of sewage contamination. Given a stream with a certain amount of pollution, the per cent of such pollution which must disappear per mile of flow will continually decrease as the stream flows on.

To return to Dr. Long's figures. The analyses as given by him are as follows, in parts per million:

At Bridgeport:

	Free Am.	Albu. Am.	Oxygen Consumed.
June 26	2.6	0.64	12.0
July 3	2.7	0.52	6.8
17	25.0	1.50	22.4
24	5.5	0.37	12.6
31	23.0	1.76	23.2
Aug. 7	26.0	1.50	16.8
14	29.0	1.64	32.0
21	27.2	1.50	28.0
28	29.2	1.90	35.2

At Lockport:

	Free Am.	Albu. Am.	Oxygen Consumed.
June 26	2.8	0.56	11.36
July 3	2.4	0.42	7.20
17	10.2	0.72	12.80
24	9.2	0.47	14.80
31	11.0	0.72	10.70
Aug. 7	12.0	0.48	9.60
14	15.2	0.88	9.76
21	15.0	0.84	10.80
28	13.0	0.88	12.40

At Joliet:

	Free Am.	Albu. Am.	Oxygen Consumed.
June 26	1.7	0.46	7.36
July 3	1.8	0.46	9.76
17	13.0	0.44	14.50
31	9.2	0.44	5.68

Aug. 7	7.5	0.42	5.84
14	9.8	0.46	5.76
21	9.0	0.11	0.52
28	8.0	0.32	6.80

Plotting these in graphic form they assume the shape shown on the accompanying charts, pages 189, 190, 191. The change in lake-level at various dates, together with other disturbing influences, caused comparatively clean water to reach the pumps at times, and we, therefore are furnished with data governing the purification of several variously contaminated waters, while flowing under constant conditions.

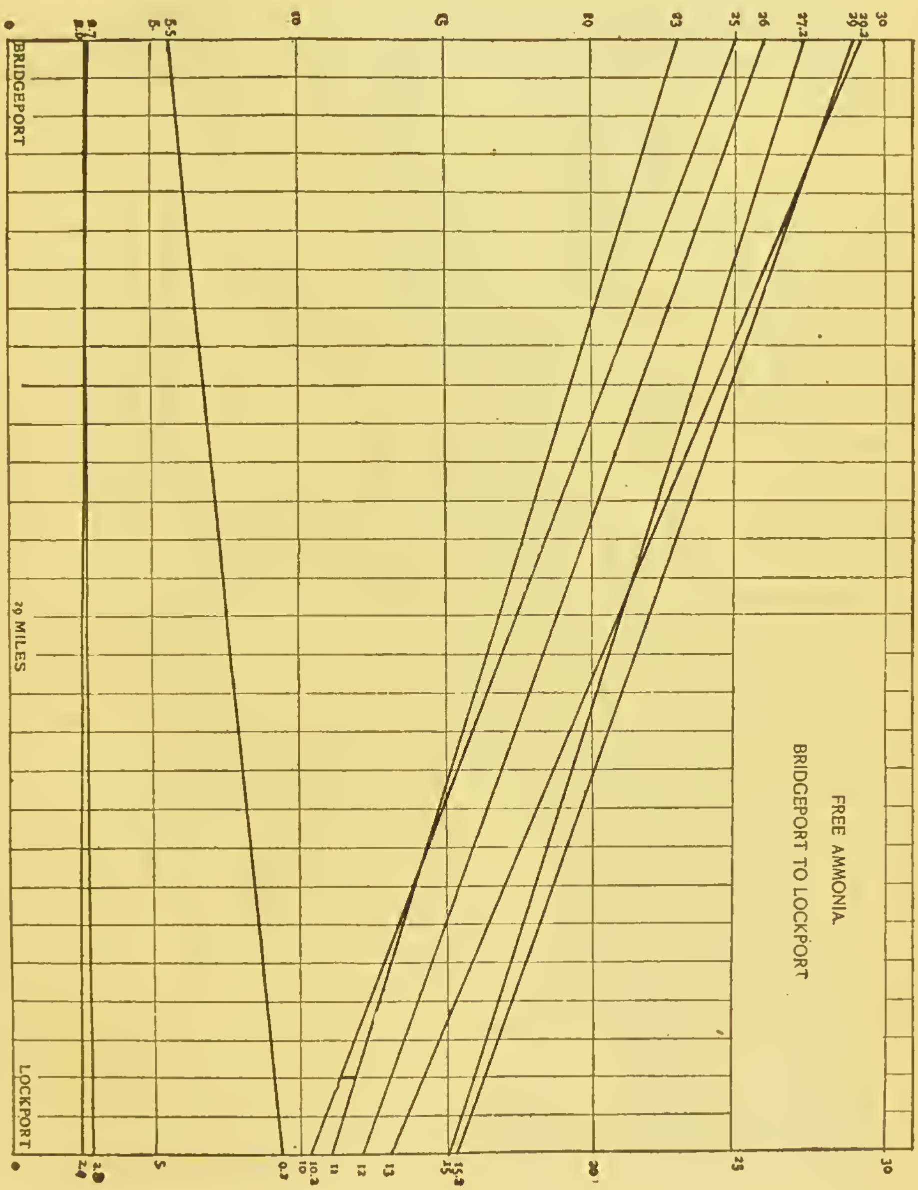
It will be noticed that the rate of purification per mile for the more grossly contaminated samples is much greater than that for those comparatively pure. Thus, during the flow from Bridgeport to Lockport the sample of July 3d loses 11.2 per cent of its free ammonia and 19.3 per cent of its albuminoid ammonia, while the sample of August 28th loses 55.5 per cent free ammonia and 53.7 per cent albuminoid ammonia while flowing the same distance.

Even the best of these waters of the Illinois and Michigan Canal is very far from being potable, and we may consequently look for still further reduction in the purification rate as we near the potable limit. My experience with the waters of large streams contaminated with city sewage leads me to the belief that self-purification is exceedingly slow.

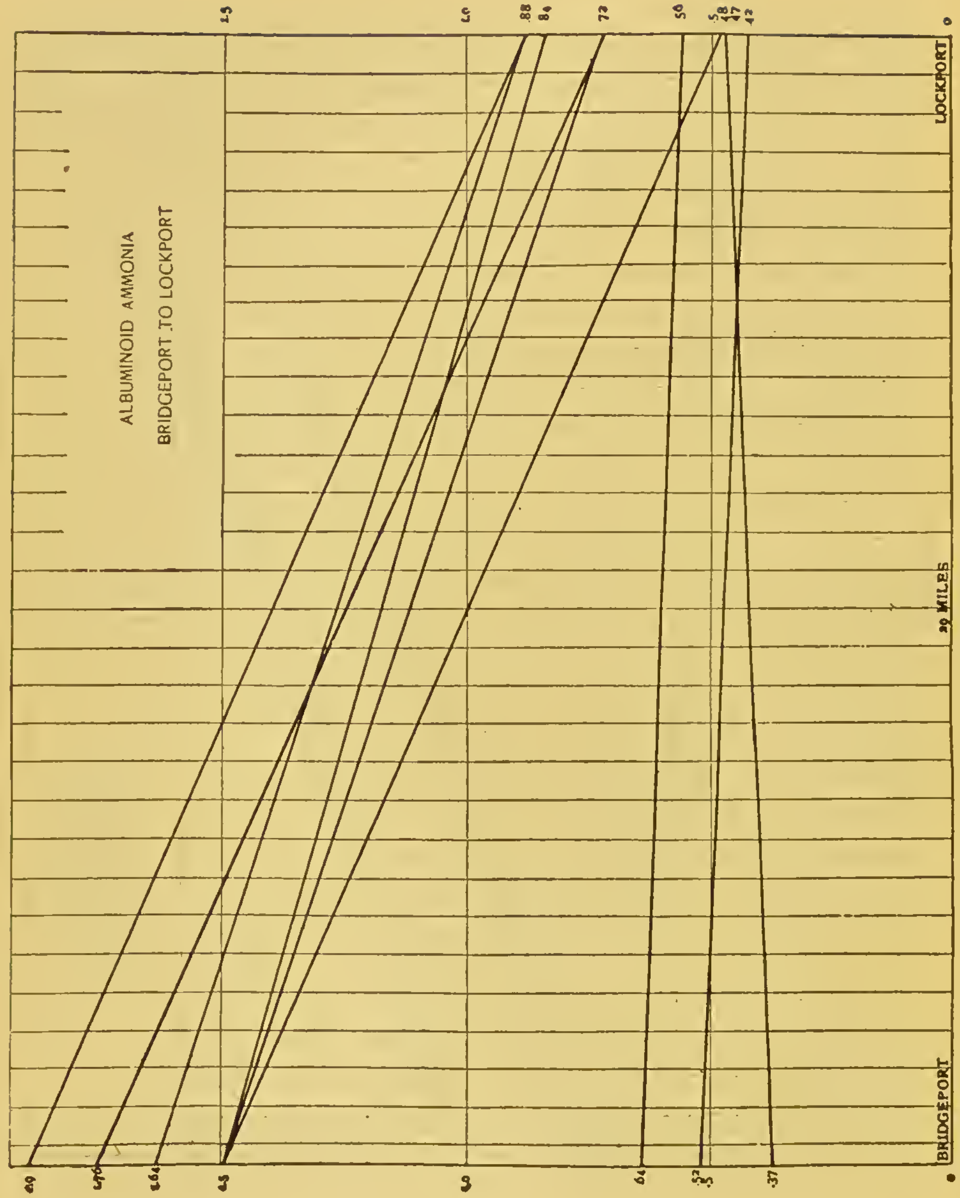
The changes which take place in undiluted sewage are very rapid, as may be seen from the table given on page 192.

In speaking of the apparent self-purification from organic matter of the river "Wear," Frankland points out that a large amount of water charged with iron from the coal-workings finds its way into the stream, and he calls attention to the potency of iron in various forms for the removal of organic matter from water.*

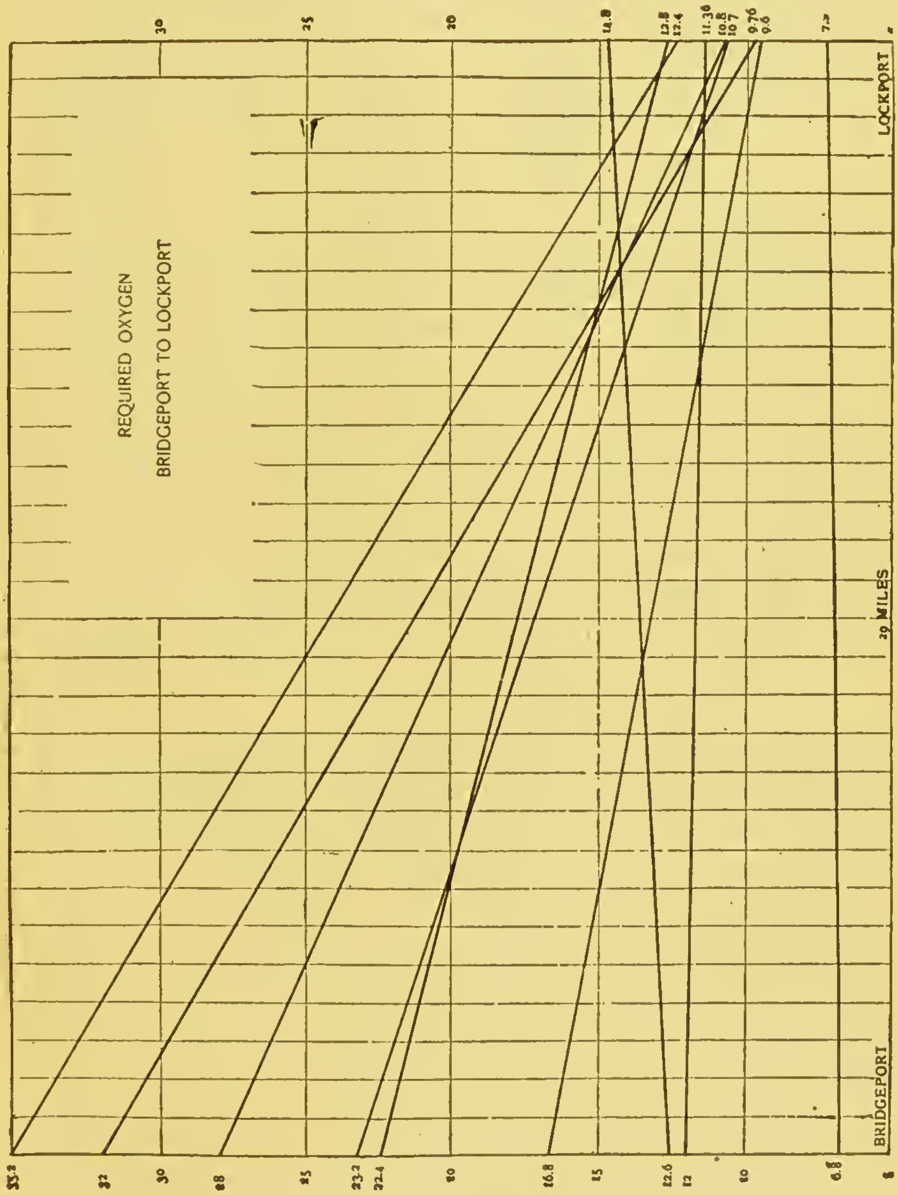
* J. Chem. Soc. XXXVII. 529.



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.



SELF-PURIFICATION IN ILLINOIS AND MICHIGAN CANAL.

CHANGES OCCURRING IN FRESH SEWAGE UPON STANDI *

Date	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrites and Nitrates.	Bacteria per c.c.
March 11, 10.30 A. M...	22.5	9.7	3.5	1,190,000
" " 12.30 P. M...	25.0	10.0	3.1	1,085,000
" " 3 P. M...	25.5	10.1	2.9	1,505,000
" " 6 P. M...	28.5	10.1	2.5	1,530,000
" 12, 8 A. M...	49.5	10.8	0.3	20,475,000
" " 12 M...	50.0	11.3	0.2	23,100,000
" " 5 P. M...	50.0	10.2	....	20,000,000
" 13, 10.30 A. M...	51.0	10.0	....	12,810,000
" 14, 10.30 A. M...	50 0	9.5	....	11,235,000
" 15, 10.30 A. M...	50.0	9 3	....	6,825,000
" 16, 10.30 A. M...	50.0	9.3	....	4,485,000
" 18, 10.30 A. M...	51.0	8.3	....	3,420,000
" 19, 10.30 A M...	52.0	8.4	....	2,341,000

We have seen that the amount of oxygen dissolved in a water need not be large in order to permit the purification changes inaugurated by nature to go on; but in the event of the supply of oxygen being entirely cut off, putrefactive reactions are set up with very undesirable results.

An interesting case of this kind is reported by Dr. Leeds as occurring during the winter of 1882–3. The exceedingly bad taste and smell of the Philadelphia water was found by him to have been due to a superabundance of putrescible material, at a time when the dissolved oxygen was unusually small in quantity. The rainfall of the late autumn and early winter had been very slight, thus producing a low state of the river. Polluted water in extraordinary quantity had been admitted by the emptying of sundry dams and canal levels, and the atmosphere was cut off from direct action upon the river by a continuous coating of ice. Under these circumstances the foul-smelling compounds well known to form when organic matter decomposes out of contact with air were produced in large quan-

* Mass. Bd. Health, 1894.

tity, to the great discomfort of the water-consumers. So considerable in amount were the gaseous products in this instance that it was possible to ignite them as they escaped from holes in the ice. The flame produced by igniting the gas issuing from a penknife-puncture of the white hollows under the ice is described as being usually six inches high, but once it was "fully a yard high."*

A curious instance of similar character was reported in the Chicago papers of November 2, 1894. Refuse matter had accumulated in so great quantities in the Chicago River that the available oxygen was far too small in quantity for its proper oxidation. Gaseous and inflammable products of sub-aqueous putrefaction resulted, which upon ignition at the surface became almost dangerous to shipping. "The tug A. Mosher was towing the schooner Ford River out of the South Fork, when both boats were surrounded by the fire, which was consuming the gases rising to the surface in huge bubbles."

Judged from the bacteriological standpoint, a considerable monthly and seasonable variation will be observed in the relative purity of running streams. During the low water of summer, although the relative volume of sewage-inflow is large, yet the absence of surface-washings, due to storms or melting snow, usually causes diminution in the number of bacteria present; yet in the case of one wide but shallow river with which the author is familiar, the summer counts exceed those of winter, especially in the vicinity of towns, owing doubtless to the great sewage addition showing itself more clearly during the stage of low water.

The river Seine at Paris shows the following variations in number of bacteria per cubic centimetre, the estimations

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* J. Frank Inst. LXXXVI. 26.

having been made at Ivry, just above the city, and at two points within the city but above the inflow from the main sewers:

	Ivry.	Austerlitz Bridge.	Chaillot.
Winter	43,500	48,890	91,128
Spring	26,570	33,440	71,845
Summer	13,710	41,635	144,650
Autumn	43,340	53,965	139,700
Mean	31,780	44,482	111,831

Percy Frankland gives the following counts of bacteria per cubic centimetre in Thames water collected at Hampton:

	1886.	1887.	18 8.
January	45,000	30,800	92,000
February	15,800	6,700	40,000
March	11,415	30,900	66,000
April	12,250	52,100	13,000
May	4,800	2,100	1,900
June	8,300	2,200	3,500
July	3,000	2,500	1,070
August	6,100	7,200	3,000
September	8,400	16,700	1,740
October	8,600	6,700	1,130
November	56,000	81,000	11,700
December	63,000	19,000	10,600

At times it chances that some substance of especially marked smell or taste becomes mingled with the general mass of sewage contaminating a water, and a lively sense of pollution immediately takes possession of the consumers. For instance, some years since, a paper-mill dumped refuse containing a little carbolic acid into a tributary of the Passaic River, at a point above the common intake of the cities of Newark, Hoboken, and Jersey City. So strong was the

odor and taste communicated to the supplies of the three cities that use of the water for drinking purposes was for a time discontinued. The quantity of carbolic acid consumed by each individual using the water was well-nigh infinitesimal and beyond possibility of doing harm, yet serious objection was made to the "pollution" of a stream which was already laden with the sewage of fifty thousand persons residing at the city of Paterson, only eighteen miles above.

Again: The city of Cleveland, O., takes its Lake Erie water from an intake situated beyond the breakwater, and the city sewage passes into the artificial harbor and thence is delivered into the lake at a point well down the east shore. It might be thought that there was little chance of sewage working so far westward against the general trend of current, but it so happens that oily material from the Standard Oil Company's works constitutes a portion of the city sewage, and it has been noticed that a petroleum taste is given the water when the direction of the wind causes an accumulation of sewage in the harbor, which sewage is afterwards permitted to rapidly escape into the lake upon change in the weather. In each of these cases the special material was but a harmless indicator of the presence of the unrecognized but far more dangerous sewage pollution, yet the public strongly objected to the one and calmly accepted the constant presence of the other.

It will be remembered that some years ago, about 1879, a portion of Boston's water-supply was considered in great danger of contamination with sulphuric acid, owing to the burning of chemical works situated upon one of the tributaries to Mystic Pond, whereby some fifty tons of oil of vitriol were washed into the stream. Mystic Pond is about eight miles below the site of the works, and mill-ponds intervene. Marked acidity was noticed at varying points in the course of the stream and intervening ponds, but no trace

of acid remained by the time Mystic Pond itself was reached.

This instance has been often dwelt upon to show how thoroughly nature takes care of even the stable inorganic additions to surface-waters; but, as a companion-picture, the following is cited as a case in which purification was not nearly so rapid.

On November 18, 1886, a cyclone struck the main building of a sulphuric-acid establishment situated in northern New York and caused several hundred carboys of oil of vitriol to escape into a small neighboring pond of 150,000 gallons capacity. Some sixty or seventy feet south of this pond, and upon a level ten feet lower, is another pond of about 450,000 gallons capacity, the water from which is used for boiler purposes by a large fertilizer manufactory. The ponds are separated by a heavy roadway embankment of, say, fifty feet in width. Undoubted and violent corrosion of new boilers having taken place at the fertilizer establishment, an investigation was inaugurated, and as a result a suit for damages was begun.

Upon analysis made by the author on February 11, 1887, nearly three months after the accident, the quantity of acid (H_2SO_4) in the lower pond was found to be 385 parts per million of water, and, as was to have been expected, the action of such water upon metals was most marked. The material through which percolation had taken place was principally shale and partly sandy soil. The outlet of the lower pond varied with the season, but was an average stream of a foot or two in diameter.

On September 26, 1887, the acidity at the outlet had fallen to zero, but in two trenches dug on the north side of the pond toward the acid-works, the acidity showed 1083 and 772 parts per million respectively.

On March 29, 1889, over two years after the accident, the water in the trenches above referred to indicated 363

parts of acid per million, and the pond itself had again become acid to the extent of 28 parts per million.

My examinations ended here, but another chemist made an examination on May 21, 1889, and found an acidity in the pond-water of 1.23 per million.

Of course these ponds are, with their small outlets, very far from being running streams, and the amount of acid originally dumped into the upper one bore a large ratio to the contained water; but when we dwell upon the Mystic Pond incident, and find that it was a question of days only until the more immediate mill-ponds freed themselves from contamination, we are impressed with the fact that nature cannot always do her work with uniform speed, and that at times her powers may be seriously overtaxed. The ponds which we have been considering did not communicate, and the acidity of the lower one was caused entirely by infiltration through considerable shaly material. The variation in acidity was doubtless due to the disturbing influence of alternately dry and rainy weather. What is most to be noted, however, is the great length of time during which the acidity lasted.

Sundry laws have been passed in various countries, from time to time, dealing with the question of prevention of river-contamination, but none of them, perhaps, is more sweeping than the German act of July 1, 1894. It prohibits the discharge into rivers of—

(*a*) Substances of such a nature that their introduction may give rise to an infectious disease.

(*b*) Substances of such a nature, or in such quantities, that their introduction may involve an injurious pollution of the water or the air, or a decided annoyance to the public.

A special officer of the province is to determine as to the things and quantities covered by this act.

The English laws, adopted upon recommendation of the Rivers Pollution Commission (see report of that body), are too long for insertion here. They are quite detailed in character and have been criticised as being too severe to be effective.

In America not so much has been accomplished along this line. At a meeting held September 25, 1894, of the American Public Health Association, the following resolutions were adopted:

"WHEREAS, It is the sense of the American Public Health Association that the pollution of potable water in America has reached such a point that the National Government should be asked to take cognizance of the matter, with the view of devising means of prevention and relief; therefore, be it

"*Resolved*, That this Association memorialize the Congress of the United States, and ask that they shall authorize the appointment by the President of a competent commission, clothed with power to fully investigate the whole subject of the pollution of rivers and lakes by municipal and manufacturing waste, and provided with sufficient means to enable them to conduct the examination in such a manner as shall be deemed best, the results of said examination to be published from time to time for the public information.

"*Resolved*, That in view of the danger to the public health by the sewage contamination of our fresh-water lakes, rivers, and streams, this Association memorialize the different federal governments, as well as the State and provincial governments, to pass laws prohibiting the contamination of these water-supplies by sewage from cities, towns, and villages, and compel them to provide some means for the treatment and oxidation of this sewage before emptying it into these places."

In Pennsylvania the State Board of Health proposed the enactment of a law from which the following is extracted:

"It shall be unlawful to put the carcass of any dead animal, or the offal from any slaughter-house, butcher's establishment, or packing-house, or any putrid animal substance, or unpurified sewage, or human excrement, or other polluting matter, such as will render water injurious to health, into the water of, or upon the ice of, any pond, lake, stream, or river in this Commonwealth used as a source of water-supply by any city, borough, or village, within thirty miles of the point where such supply is taken, or to place any of the said polluting substances on the banks of any such pond, lake, stream, or river, or the feeders thereof, within five miles of the point where such supply is taken.

"The State Board of Health shall have the general supervision of all springs, wells, ponds, lakes, streams, or rivers, together with the waters feeding the same, used by any town, village, or city as a source of water-supply, with reference to their purity, and shall examine the same from time to time and inquire what, if any, pollutions exist, and their causes."

Highly desirable as it would be to keep the waters of our great rivers in their natural condition of potable purity, the enormous expense of attaining to even an approximation to that state of things should be considered, and the possibility of causing great injustice to established institutions must be also borne in mind.

Very large centres of population are already in existence which turn their sewage directly into the river upon the banks of which they stand. The up-stream city might well complain should it be forced, at great expense, to establish sewage-disposal plants, when the town below, for much less money, could secure a superior water from some pure inland source.

To the author's way of thinking, a land should be looked upon as watered by its smaller lakes, its springs, and its

brooks, and sewered by its great, especially its navigable, rivers. Its water-sources should be protected by law with exceeding care, and no river or stream should be added to its list of drains except after proper consideration by the State Board of Health, followed by legislative permission.

CHAPTER V.

RAIN, ICE, AND SNOW.

SAUSSURE has shown that a part of the water raised into the atmosphere resembles soap-bubbles.

Clouds are composed of small vesicles, of which water forms the envelope. Every vesicle that rises from the sea must contain a small quantity of the solid matter which was dissolved in the sea-water. Similar vesicles also form on lakes, streams, and rivers, and the proportion of solid matter taken up in a given space will vary according to the relative proportions of these original vesicles that enter into the composition of the clouds.*

Beyond this stated source of solid matter in rain-water, there is to be considered the large quantities of dust of all kinds continually carried into the atmosphere by the winds, and washed out therefrom by the falling drops. In the vicinity of large towns, various products of incomplete combustion and of industrial waste are added to the atmospheric impurities, and are precipitated along with the more commonly occurring dust.†

The presence of soot in the air causes increase in the rain-water of such impurities as sulphuric acid and ammonia, by what appears to be direct absorption of such material by

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* Angus Smith, " Air and Rain," 233.

† The English Alkali Act permits the presence of HCl to the limit of 0.2 grains, and of SO_3 to the limit of 4 grains in each cubic foot of air, taken at the foot of the stack of such industrial plants as generate such waste-products.

the soot. This is shown by Mabery in the following analysis of the air of Cleveland, Ohio: *

WEIGHT IN MILLIGRAMMES, PER LITRE OF AIR.

Soot.	Sulphuric Acid.	Ammonia.
87.5	15.2	.070
45.2	6.3	.010
111.3	21.2	.120
41.8	13.9	.003

On September 8, 1894, there occurred the first rain, after the longest period of drought that had been experienced in the State of New York during forty years. Many forest-fires had occurred, and the atmosphere had been exceedingly hazy for weeks.

The author collected rain-water, on the above date, in the Catskill Mountains, and the quantity of oily, sooty material it contained was very striking.

The presence of iodine in the rain and surface-waters of certain districts has been known for years, and it has been claimed, but not satisfactorily proven, that there is a relation between the occurrence of goitre and cretinism and the absence of iodine in the drinking-waters of the places where such diseases are most commonly found.†

The various germs floating in the air, and ready to be carried down by the first shower, do not play a very material *rôle* from the hygienic standpoint, partly because of the improbability of their being pathogenic in character, and partly because of the germicidal power of the direct sunlight to which they have been so thoroughly exposed.

Nevertheless, it may be of passing interest to give the latest official figures issued by the Montsouris Observatory, France:

* J. Am. Chem. Soc. XVII. 3.
† Angus Smith, "Air and Rain," 241.

BACTERIA PER CUBIC METRE OF AIR AT MONTSOURIS.

(Average for ten years.)

January	160
February	145
March	225
April	310
May	305
June	355
July	465
August	455
September	310
October	190
November	195
December	165
Mean	275

A comparison of country and city air shows the following number of bacteria per cubic metre:

Montsouris	275
Centre of Paris	6040

There is a daily maximum of bacteria at 2 P.M and a minimum at 2 A.M.*

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* Miquel gives the following interesting comparison, in terms of bacteria per cubic metre, between the air of the Paris sewers and that of the public streets:

	Air of the Sewers.		Air of the Streets.	
	Bacteria.	Moulds.	Bacteria.	Moulds.
Winter	2,385	4,050	3,210	599
Spring	7,165	2,330	11,085	865
Summer	5,110	2,730	12,070	2,340
Autumn	5,400	1,550	7,365	2,320
Mean	5,015	2,665	8,435	1,530

An interesting observation was made upon the air of the St. Antoine hospital, Paris, showing how large a fraction we retain of the bacteria we respire:

	Bacteria per Cubic Metre of Air.
Before respiration	20,700
After "	40

As would have been expected, the Montsouris observations found that the amount of carbon dioxide present in the air of the city was greater during the day, while in the country these relations were reversed.

Rain-water collected twenty-five miles from London is reported as giving the following analytical results, for an average of seventy-three samples:

Organic carbon....................	.99 per million.
Organic nitrogen................	.22 " "
Ammonia.......................	.50 " "
Nitrogen as nitrates and nitrites...	.07 " "
Chlorine.......................	6.30 " "
Total solids	39.50 " "

Filhol found the following amounts of ammonia in rain-water collected near the city of Toulouse:

January....................	0.60 per million.
February...................	0.82 " "
March	0.83 " "
April......................	0.44 " "
May.......................	0.55 " "
June......................	0.77 " "

In the city of Toulouse itself the reading for February was 6.60 per million.

These figures show the marked difference between city and country rain.

Angus Smith and Boussingault place the average amount of ammonia in the rain of temperate climates as 0.5 per million.

The monthly variation in the chlorine contained in rain-water collected at Troy, N. Y., is given in the following table, the determination having been made in a mixture of the entire rainfall for each month:

January	2.50 per million.
February	1.07 " "
March	1.55 " "
April	0.75 " "
May	1.25 " "
June	1.15 " "
July	1.05 " "
August	2.00 " "
September	0.60 " "
October	3.00 " "
November	2.25 " "
December	2.50 " "
Mean	1.64 per million.

Even casual inspection will often show that rain-water is a long way from being chemically pure, and, high as this "water from the heavens" is rated in the public mind, it is frequently polluted, when delivered for use, to an extent quite surprising to the collector of the supply.

The author has often noted the confidence with which people will make use of water from a foul cistern, even when the odor of the water is strongly objectionable, because of entire faith in the purity of its original source.

Thus water from a dirty cistern in West Troy showed the following analysis. In appearance the water was good.

Free ammonia	1.050 per million.
Albuminoid ammonia	.175 " "
Chlorine	2.000 " "
Nitrogen as Nitrites	strong trace
Nitrogen as Nitrates	0.0 per million.
Required oxygen	2.25 " "
Total residue	20.00 " "

The roof upon which the rain is caught is a twofold cause of impurity in the collected water; first, because of

the material of which it is composed, and, second, bécause of the foreign substances that may settle thereupon.

In cities, the amount of street-dust blown upon the roof, and afterwards washed into the cistern, is much greater than is commonly supposed. Soot, excrement of birds (often a large item), fallen leaves, and various mossy growths are among the sundry additions to be found in a roof-collected water.

A question of the first importance in considering a rain-water supply is the material out of which the walls of the storage cistern are to be made. Slate or stone-ware naturally suggest themselves as the most suitable materials, but they are not often available, especially if the cistern be a large one. Cement linings, particularly for underground structures, are by far the most common, and the objection that the lime in them may somewhat increase the hardness of the water is not of much weight, in view of their convenience and low cost.

Tanks of wood serve their purpose well, provided they be kept full; but if there be great fluctuation in the water-line, organic development is liable to occur, and the tank itself falls out of repair. The city of New Orleans possesses many tanks of cypress-wood.

Cisterns of metal are open to a number of objections. Iron rusts and colors the water; lead is dissolved by rain-water very energetically, and is consequently highly objectionable; zinc is attacked, and also galvanized iron. Tin would be a suitable metal, but pure tin would be too expensive, and "tin-plate" would not be sufficiently substantial for such use.

When the controlling circumstances demand a metallic-lined cistern, the metal chosen should be thoroughly coated with a good asphaltum paint.

The commonly employed delivery-pipe which dips into,

and remains in permanent contact with, the water of the cistern, should also be coated within and without like the cistern walls.

It is exceedingly important that every cistern should be inspected and cleaned frequently, and upon no point does the public require more instruction than this. The writer could give instances of the grossest kind of pollution of cistern-water, arising from ignorant neglect of what would seem very simple and self-evident precautions.

One form of underground cistern which has been very widely favored in the past is that belonging to the "filtering" type. It is constructed by simply dividing the cistern into two chambers by a vertical brick-wall. Water enters one of these divisions and is drawn from the other after percolation through the dividing wall. Such an arrangement cannot be too strongly condemned. The wall is a mere strainer at the best; it cannot be properly cleaned, and it gives a very false sense of security. The very worst case of contaminated water the writer ever saw came from just such a cistern.

The suitable location of an underground cistern is a matter that one might think could be safely left to the good sense of the average householder; but such is very far from being the fact. The writer examined one case in which, on account of a defective lining and a leaky sewer, a portion of the house-drainage was returned to the house along with the cistern-water and used for household purposes. In another instance an inclined cesspool was observed located in a bank ten feet *above* and fifteen feet to the west of the pit furnishing the family's supply of water.

Dr. Smart made a valuable report to the National Board of Health on the rain-water supply of New Orleans, in which he says that he found the wooden cisterns frequently lo-

cated "in unventilated inclosures, rank with the emanations of unclean privies."

While its softness recommends it for use in the laundry, and while the absence of lime-salts renders it desirable for cooking, rain-water is, on the whole, not to be considered so suitable as a pure ground or surface-water for general domestic supply.

Ice, especially in America, is unquestionably to be ranked as an article of food, and the enormous quantity of it consumed may be inferred from the fact that very recently an "ice trust" has been established, under the laws of Maine, with a capital of twelve and a half millions of dollars.

Throughout the colder sections of the country "natural ice" controls the market almost completely, and the dealers supplying the same "harvest their crop" from the first sheet of water they find conveniently located, without the least inquiry as to its suitable condition; thinking, if they think at all, that the process of freezing eliminates all objectionable features that the water may chance to possess. The author has examined ice from ice-houses deriving their supplies from canals, barnyard ponds, and the like—localities from which no one would ever dream of drawing a supply of water. To show the thoughtlessness of some of the large dealers, let it be said that in the short reach of the Hudson River extending from Troy to Coxsackie, a distance of twenty-seven miles, there are sixty-eight large ice-houses, storing 1,408,000 tons of ice. All of these houses take their ice from the river within the influence of the sewage of the cities of Troy and Albany and of various smaller towns.

There is a law of Massachusetts, enacted in 1886, to prevent the sale of impure ice:

"Upon complaint in writing of not less than twenty-five consumers of ice which is cut, sold, and held for sale from

any pond or stream in this commonwealth, alleging that said ice is impure and injurious to health, the State Board of Health may appoint a time and place for hearing parties to be affected, and give due notice thereof to such parties, and. after such hearing, said board may make such orders concerning the sale of said ice as in its judgment the public health requires."

Reference has already been made (page 180) to the small quantity of purification to be expected from the freezing of water when judged by chemical standards; and Dr. Prudden has also shown how very imperfect the result is when viewed as a bacteriological question.* He gives the following experimental results for the bacillus of typhoid fever:

	Bacteria per Cubic Centimetre yet living in the melted ice.
Before freezing	Innumerable
Frozen 11 days	1,019,403
" 27 "	336,457
" 42 "	89,795
" 69 "	24,276
" 77 "	72,930
" 103 "	7,348

Also:

Before freezing	378,000
Frozen 12 hours	164,780
" 3 days	236,676
" 5 "	21,416
" 8 "	76,032

He found alternate freezing and thawing more fatal to bacterial life than a more prolonged period of continuous freezing.†

* *Medical Record*, March 26, 1887.

† Professor Dewar finds that bacterial life is very little affected by low temperatures. He says: "I have submitted putrefying blood, milk, seeds, etc., for the space of an hour to a temperature of − 182° C." (i.e., the boiling-point of liquid oxygen) "but found that they afterwards went on putrefying or germinating, as the case happened to be."

As concerning the relative merits of transparent and snow ice, Prudden gives the following determinations of bacteria per cubic centimetre contained in two varieties of ice cut from the same cake:

	Bacteria per Cubic Centimetre in the melted ice.
Transparent ice	46
Snow-ice	10,020
Transparent ice	3,192
Snow-ice	15,624
Transparent ice	2,322
Snow-ice	55,062
Transparent ice	218
Snow-ice	9,690
Transparent ice	918
Bubbly-streak ice	26,049

The white ice is richer in bacteria, because it contains large quantities of air, and therefore is capable of more readily supporting the aërobic varieties.

After extended experiments with both harmless and disease-producing bacteria, Prudden concludes:

"While no absolute percentage of destruction can be given which will indicate the degree to which water containing bacteria usually purifies itself from them in the act of freezing, experimental data justify the belief that in ordinary natural waters there may be a purification of about ninety per cent.* The effect of freezing may in a general way be compared to that of filtration, but there is a very significant difference between them. By filtration, the various species, dangerous and harmless, are eliminated with about equal efficiency, while in the purification by freezing the dangerous disease-producing species may be retained,

* Bordoni Uffreduzzi finds that ice taken from the river Dora at Turin always contains ninety per cent less organisms than the river-water.

while more or less of the harmless forms may be destroyed. Freezing may act as a selective filtration." *

The slower the formation of ice, and the deeper the water on which it forms, the better will be its quality, other things being equal. As the rate of formation decreases as the ice thickens, it follows that the lower portion of a thick layer is purer than the upper. Dr. Drown has strikingly shown the progressive improvement in quality from the top downward, by the analysis of successive fractions of a block of ice which was divided into five layers.

It is a widespread habit among ice dealers to cut holes in the ice-field and permit the water to flood the field and freeze on top. The thickness of the "crop" is rapidly built up by this means, but the water so frozen is frozen as a whole, and the impurity of the resulting ice is necessarily equal to that of the water from which it is formed.

Similar objection is properly made to the ice from very shallow ponds and flooded meadows, for there is manifestly in these cases little or no chance for the impurities of the water to free themselves from the thickening ice, which frequently forms to the very bottom of the pond.

A widely talked-of instance of illness produced by ice occurred some years ago at Rye Beach, N. H. The contamination of the ice, which was gathered from a marsh, seemed to have been marsh-mud and decomposing sawdust. The data given the author by the local physician stated that during the season some five hundred people at the hotel consumed this ice for six weeks. "Of these, twenty-six adults were known to manifest grave and continued symptoms. A large number, probably the majority of the guests, drank the contaminated water with apparent impunity." No one under

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† See also page 180.

the age of ten years was afflicted. The symptoms were giddiness, nausea, vomiting, diarrhœa, severe abdominal pain, fever, loss of appetite, and mental depression. The analytical results were:

	Ice.	Pond-water.
Free ammonia	.208	.197
Albuminoid ammonia	.704	.597
Mineral residue	78.0	649.6
Organic residue	57.2	80.0
Total residue	135.2	729.6

Finally, let it be distinctly stated that the only proper rule to follow is never to harvest ice from a source from which it is unsafe to drink the water.*

Artificial ice is making very rapid strides toward popularity, and if its manufacturers would confine themselves to the use of distilled water as a basis for their product, there is no question but that the confidence of the people would be well placed and permanently retained.

Unfortunately there is a quantity of artificial ice offered for potable use that is made from very ordinary water; and, inasmuch as the method of formation causes the water used to freeze as a whole, all the impurities of the water are retained and concentrated in the centre of the cake of ice, that being the last portion to solidify. Unless the water employed be distilled, artificial ice must, of necessity, be more impure than natural ice frozen from the same water.

Snow can be considered only as an indirect source of water-supply, but as such it assumes a position of some importance. The water from melted snow is commonly more im-

* It is curious to note that the ice-supply for the island of Teneriffe is obtained from a cave 100 feet long, 30 feet broad, and 10 to 15 feet high, situated on the "Peak," 10,000 feet above the sea.

pure than rain-water from the same locality, for the reason that its flakes act better than the spherical rain-drops for entangling impurities suspended in the atmosphere, and their low temperature is conducive to the absorption of ammonia. Analyses of city and country snows from the same general locality show marked differences which are illustrated in the results obtained from samples gathered in the open country and in the city of Troy, N. Y.:

	City Snow. (Troy, N. Y.)	Country Snow. (Menands Station.)
	Parts per million.	Parts per million.
Free ammonia	.460	.15
Albuminoid ammonia	.225	.06
Nitrogen as nitrates	.200	Trace.
Nitrogen as nitrites	Trace.	Slight trace.
Chlorine	1.87	.60
Required oxygen	1.90	1.00

Of course, as is the case with rain, the first portion of the fall must always contain the greatest amount of impurities. The chlorine in city snow (Troy, N. Y.) was thus found to vary during the same storm of two day's duration.

First day	3.05	parts per million.
Second day	2.55	" " "

London snow was found by Coppock* to contain:

Total solids	237.3	per million.
Mineral matter	89.3	" "
Carbonaceous matter	156.5	" "
Free ammonia	66.3	" "
Albuminoid ammonia	93.0	" "

The first half of the above-referred-to snowfall contained

* *Chem. News*, LXXI. 92.

seventy-five per cent of the impurities. The carbonaceous matter was ordinary soot.*

After snow is once upon the ground it changes in composition quite rapidly, particularly in its contained ammonia. This change is, however, greatly influenced by the character of the surface upon which it rests.

Thus, the tendency of snow to absorb impurities from the soil is shown by the following comparative analyses of samples taken from a roof and from a meadow:

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Required Oxygen.	Total Residue.	Loss on Ignition.
Fresh snow from roof	.50	.15	.80	trace	trace	.50	22.	7.
Same snow after lying on roof two days..	1.24	.21	.85	trace	trace	2.85	64.	21.
Fresh snow from meadow	.27	.11	.75	trace	trace	.40	41.	12.
Same snow after lying in meadow two days..............	.79	.26	.70	trace	trace	2.70	65.	29.

Additional force is thus given to the saying, "Snow is the poor man's fertilizer," and "The fogs and snow remain to fatten the land."

The great influence that melting snow has upon spring-water is shown by the following analyses of a flow from a spring in Rensselaer County, N. Y. The water serves as an illustration, although it is not a "normal" water, as is seen from the high chlorine. (See table, top of opposite page.)

The wholesomeness of snow-water has been gravely questioned by a number of investigators;† notably by Dr. Chas. Smart, of the U. S. Army. He holds that the malarious

† Tissandier refers to cosmic dust found in Paris snow. Boussingault found in water from a heavy fog, which had lasted two and a half days, fifty parts of ammonia per million.

	Oct. 15.	Nov. 10.	Dec. 15.	Jan. 12.	Feb. 5.	March 2.	April 6.	May 8.	June 5.
Free ammonia.........	trace	trace	.015	.010	.025	.027	.025	.01	.01
Albuminoid ammonia..	.036	.03	.055	.035	.090	.078	.060	.04	.07
Nitrogen in nitrites....	.000	.000	.000	.000	trace	.000	.000	.000	.000
Nitrogen in nitrates....	.116	.075	.15	.15	trace	.30	.15	trace	.05
Chlorine.........	20.5	17.3	19.	19.	21.	20.	21.5	18.	17.
"Required oxygen"...	.000	.1	.4	1.15	1.5	1.0	.3	.1	.5
Total solids..........	570.	570.	558.	534.	579.	543.	554.	553.	552.
Loss on ignition.......	.....	79.	62.	44.	114.	73.	63.	48.	52.
Temperature F°.......	53.6	49	46.4	44.6	41	43.7	42	50	51.8
Bacteria per c.c........	158.	750.	1620.	2519.	166.	8520.	476.	.....	.....

poison contained in such water is to be counted as the cause of mountain-fever.*

A detailed account of an outbreak of "aqua-malarial," or mountain-fever, among U. S. troops stationed in Utah, is given in Buck's "Hygiene," page 132. The disease is ascribed to the use of snow-water, and it is stated to be a widely-known fact among the native trappers that free use of water derived from the melting snow in the spring will produce the disorder. It is difficult, however, to entirely eliminate the influence of cold nights and hot days with free use of ice-cold water, from the presumed effect due alone to the snow.

Dr. Frederick A. Cook,† the ethnologist of the Peary North Greenland Expedition, tells us that the northern Eskimo lives wholly on meat, about two-thirds of which he eats raw or frozen. The men are about five feet one and a half inches high, and weigh about one hundred and thirty-five pounds. They drink melted ice or snow for their water for ten months out of the twelve, and really have only two months out of every year of a virile existence. They never wash, and beyond a little rheumatism or a mild attack of *la grippe* they enjoy good health. They are fat and rounded like little seals.

* *Am. J. Med. Sci.*, Jan. 1878.

† *New York Jour. of Gynecology and Obstetrics.*

CHAPTER VI.

RIVER- AND STREAM-WATER

A VERY large number of cities derive their water-supplies from rivers—in Europe after careful filtration, but in America usually without such purification.

One of the important things for the consumer of such a water to bear in mind is that sudden and great changes in the character of the water are to be expected.

For instance, the water of the Hudson River, sampled at a point above direct sewage-inflow (although below several large towns), shows the following variations:

	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	"Required Oxygen."	Total Residue.	Loss on Ignition.	Suspended Matter. (Silt.)	Temperature, F°.
1894.										
Nov. 3.	.030	.087	000	trace	3.5	3.76	73.	35.	88.4	......
Dec. 15	.045	.150	trace	.15	4.5	13.00	107.	42.	68.8	36.
1895.										
Jan. 12.	.025	.080	000	.10	3.5	7.65	43.	39.	000	......
Feb. 5..	.055	.100	000	.15	......	8.85	88.	45.	000	34.6
March 4	.085	.150	trace	.10	......	10.00	93.	51.	000	33.
April 5.	.042	.235	trace	.30	2.4	5.90	388.	88.	11.	46.4
April 10	.058	.660	trace	trace	.....	15.50	583.	74.	495.	41.
May 8..	.030	.205	trace	.10	2.5	7.30	67.	31.	000	68.
June 5..	.045	.120	000	trace	3.5	8.70	78.	50.	000	71.
Sept. 20	.280	.320	.0015	.30	5.0	2.65	......	......	......	......
Oct. 30.	.055	.155	trace	......	3.5	14.85	101.	57.	000	44.

A river-water which is clear to-day may be muddy and less fit for use to-morrow.

Another change, slow in operation but serious in result, is that induced by the establishment of sewerage systems in

up-stream cities, through the growth of the population, which naturally sewers into the river. Touching this latter point, the author reported as follows upon a river-water proposed for city supply:

"Its analysis to-day is far from being a measure of its sanitary condition a few years from now. The cities and towns above are beginning to put in sewers, and the day is not far distant when the river will be marked by the inferiority of its water."

Fischer gives the following seasonable variations for the water of the Danube:

	Suspended Material.	Dissolved Material.
Spring................	121.9	177.1
Summer..............	165.4	146.0
Autumn..............	76.5	178.6
Winter................	14.8	199.0

He found the Rhine water to vary between these limits for high and low water in 1886:

Suspended material	249 to 12
Dissolved material..................	246 " 203

Klinger's results for the river Neckar are:

		Suspended Material.	Dissolved Material.
March	1888.........	373	272
April	"	0	382
June	"	0	400
August	"	0	397
September	"	65	440

It is to be noted that the bulk of variation lies in the item of suspended material, and that what is in solution is much more constant in amount.

Below is a statement of the number of days in each

month, for 1891, that the Hudson River at Troy was "dirty" with suspended silt:

January	17 days
February	24 "
March	29 "
April	30 "
May	0 "
June	0 "
July	5 "
August	3 "
September	0 "
October	0 "
November	17 "
December	31 "
	156 days

The influence of autumn rains and the melting snows of winter is here well illustrated. The subjoined table is extracted from the *Engineering News* of August 10, 1893, and shows what a large item the suspended matter of a river may amount to when considered in the aggregate.

"The first column gives the name of the river; second,

DISCHARGE AND SEDIMENT OF LARGE RIVERS.

River.	Drainage Area, Square Miles.	Mean Annual Discharge, second-feet.	Sediment.			
			Total Annual, Tons.	Ratio by Weight.	Height Column, one square mile base, feet.	Depth over Drainage Area, inches.
Potomac	11,043	20,160	5,557,250	1 : 3,575	4.0	.00433
Mississippi	1,214,000	610,000	406,250,000	1 : 1,500	291.4	.00288
Rio Grande	30,000	1,700	3,830,000	1 : 291	2.8	.00110
Uruguay	150,000	150,000	14,782,500	1 : 10,000	10.6	.00085
Rhone	34,800	65,850	36,000,000	1 : 1,775	31.1	.01071
Po	27,100	62,200	67,000,000	1 : 900	59.0	.01139
Danube	320,300	315,200	108,000,000	1 : 2,880	93.2	.00354
Nile	1,100,000	113,000	54,000,000	1 : 2,050	38.8	.00042
Irrawaddy	125,000	475,000	291,430,000	1 : 1,610	209.0	.02005

its drainage-area in square miles; third, the average annual discharge of the river in cubic feet per second. The fourth column gives the total amount of sediment, in tons, annually transported by the river; fifth, the ratio of the weight of this sediment to the weight of the water annually discharged; the sixth, the height of a column in feet, having a base of one square mile, that the sediment would cover; and the seventh, the depth in inches that the drainage-area would be covered if this total amount of sediment should be spread over it. The discharge and drainage-areas of the Rhone, Po, Danube, and Uruguay are taken from a paper by John Murray in the *Scottish Geographical Magazine* for February, 1887. The drainage-area of the Nile was measured by planimeter from the best maps obtainable."

River-waters contaminated with special and unusual materials are at times met with. Thus, the well-known Rio-Vinagre of South America contains 1100 parts of free sulphuric acid and 1200 parts of free hydrochloric acid per million of water. The quantity of free sulphuric acid carried by it to the sea is over fifty tons daily.

Some streams of Norway and Sweden furnish water so impregnated with infusion of woody material as to be destructive of fish. Frankforter found "tannates" and "gallates" in the water of the upper Mississippi, due to the enormous number of logs floated down the stream from the great forests of the North.

Judged also from the bacteriological side, flowing water will always show large variation in composition at different times, principally due to introduction of impurities carried down by storms from surface-sources. Variation will also be noted at different points of the length, breadth, and depth of the same stream, as common judgment would ex-

pect, arising from irregularities in mixing of tributary waters, and from changes in the rate of sedimentation.

Dr. Beebe, of the New York City Board of Health, finds the bacteria in Croton water greatly increased after a storm. The increase is noted at the city hydrants about two days after the rain has fallen on the watershed.

Ordinarily, the bacteria are about 350 per cubic centimetre, but a hard rain will raise the number as high as 7200 per cubic centimetre.

Tidal action has also much influence upon the variation in character of certain river-waters. The author has in mind several cities, situated upon large streams, which pump fairly good water during ebb-tide, but whose sewage is carried up stream by the reversed current of flood-tide, to and beyond the intakes, with exceedingly bad results.

All such points are to be considered when selecting the position for a city's intake.

Herewith are given recent French results, showing influence of flow upon bacterial contents of river-water:

BACTERIA PER CUBIC CENTIMETRE IN SEINE WATER DURING A FLOW OF SEVENTY-FIVE MILES.

Corbeil		14,000
Choisy le Roi		67,000
Port a l'Anglais		75,000
Paris:	Austerlitz	142,000
	Alma	438,000
	Auteuil	775,000
	Boulogne	327,000
	Suresnes	252,000
Asnières		401,000
St. Ouen		2,040,000
St. Denis		1,562,000

Argenteuil	3,576,000
Poissy	391,000
Mantes	307,000

As supplementary to what has already been said regarding the self-purification of streams, a word may be added touching upon results obtained during an investigation, with which the author was connected, for the New York State Board of Health.

The original intention with which this investigation was started having been to map out the zones of sewage contamination in the Mohawk-Hudson system, from the source of each river to Poughkeepsie, so that definite information could be secured as to the length of run required for the disposal of up-river sewage, and the relation of such self-purification to the question of the use of river-water for city supply, it is hardly necessary to state that the results, so far obtained, are but the small beginning of the great mass of data required for such broad generalization.

Meagre though they be, however, they are not without considerable value, and this is particularly true of the bacteriological results, as prepared by Professor J. H. Stoller.

The point already made, that the rate of self-purification varies directly as the extent of contamination, was based upon chemical considerations (page 187), but it receives confirmation from the bacteriological standpoint, judging from Professor Stoller's determinations. The conclusions made evident by his work are:

1st. The flow of six miles between Troy and Albany does not dispose of the contamination introduced at the former place.

2d. The very gross pollution caused by the sewage of Albany rapidly lessens during the following ten miles, after which the residual impurity continues nearly constant.

This is in accord with the principle advanced during discussion of the Chicago results, page 186.

That the said " residual impurity " is an important matter, even after the flow of many miles, may be seen upon consulting such statistics of water-borne disease as have been already given.

RAINFALL, EVAPORATION, AND FLOW OF STREAMS.

Rainfall is greatest within the tropics and near the sea, and it lessens near the poles. The average annual precipitation for the north temperate zone is usually estimated as 35 inches.

" On the southerly slope of the Himalayas, northerly of the Bay of Bengal, at an elevation of 4500 feet, the rainfall for 1851 was 610 inches." (Fanning.) Of this amount 147 inches fell during the month of June.

Crooks gives the following averages for annual rainfalls in inches:

Madrid	10
Vienna	18
St. Petersburg	18.4
Stockholm	20.4
Berlin	22.8
Paris	22.8
Hanover	23.2
London	25.2
Rome	31.2
Genoa	47.2
Bombay	79.2
Havana	92.4
St. Domingo	109.2

Wooded heights have usually much more precipitation than the plains, and, according to Frautrat, rainfall is greatest in evergreen forests.

Exceptionally heavy rainfalls are not, for our purpose, especially worthy of record; but it may be interesting to note, very briefly, the following instances reported by the U. S. Chief Signal Officer.*

A rain at Central City, Gilpin County, Cal., on August 8, 1881, caused a depth of water of from four to six feet in the main street.

At Wickenburg, Arizona, on August 6, 1881, in five hours, a dry river-bed became a torrent, running ten miles per hour, a mile wide, and from two to fifteen feet deep.

At Rio Grande City, Texas, in May, 1885, in eleven hours, the Rio Grande River rose twenty feet, extending its width from one hundred yards to five miles.

A further list of very heavy rainfalls may be found in Rafter and Baker, "Sewage Disposal," page 134.

"Mr. R. de C. Ward (*Am. Met. Jour.*, March, 1892) states that in the memoirs of Benvenuto Cellini there is mention of the fact that an impending rainstorm was averted in the year 1539, on the occasion of a procession in Rome, by firing artillery in the direction of the clouds, which had already begun to drop their moisture. M. Arago, the eminent French astronomer, states that as early as 1769 it was the practice in certain towns in France to fire guns to break up storms, but he expressed doubt as to the effectiveness of that method. There have been numerous learned dissertations published by the scientists of Europe within the last two centuries relative to the possibility of breaking the force of storms by the use of explosives, and the question seems to have been settled by a negative conclusion.

In this country in recent years the question has assumed the opposite form, and the popular belief in the efficacy of

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* Senate Doc. 91, 50th Congress.

explosives as rain-producers has stimulated scientific inquiry and led to some costly experiments under government auspices. The basis of this theory is the statement, which large numbers of people accept as true, that great battles have been generally, if not invariably, closely followed by storms.

This belief is deeply rooted in the popular mind, somewhat like the various notions held by many people in relation to the effects of the moon's phases upon the weather. And it appears to be a traditional idea, for the belief that battles cause rain was prevalent before the invention of gunpowder.

Plutarch says, "It is a matter of current observation that extraordinary rains generally fall after great battles": and he accounts for it on the supposition that the vapors from blood steam forth and cause precipitation, or that the gods mercifully send rain to cleanse the earth from the stains of warfare.

While the question of rain-making by the use of explosives was under consideration at Washington the scientists of the Department of Agriculture made a thorough investigation of the subject, with all the records of the government at their command, and the conclusion reached was that there is no foundation for the opinion that days of battle were followed by rain any more than days when it was all quiet along the lines." *

Regarding the relation of great fires to rainfall, Prof. I. A. Lapham, of the U. S. Signal Service, writes of the Chicago fire as follows:

"During all this time—twenty-four hours of conflagration upon the largest scale—no rain was seen to fall, nor did any fall until four o'clock the next morning; and this was not a very considerable downpour, but only a gentle rain that ex-

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* Sage, Iowa Weather and Crop Service.

tended over a large district of country, differing in no respect from the usual rains. It was not until four days afterward that anything like a heavy rain occurred. It is, therefore, quite certain that this case cannot be referred to as an example of the production of rain by a great fire." *

The following chart and statistics † show the normal rainfall for the United States, and also the same data for separate states.

"In general, the rainfall decreases with the elevation above sea-level. This is very noticeable in passing along the parallel of latitude 40°.

"A very remarkable feature in the rainfall of the United States, appearing on most of the monthly maps, and distinctly on the annual map, is the way in which certain peaks and ranges of mountains are outlined by the mean rainfall.

"Another series of facts of very great interest can be read from the maps in the consideration of the relations of rainfall to the leeward and windward sides of the ranges. This is by far the best marked on the Pacific coast, where the prevailing winds are distinctly from the west and reach the coast laden with moisture from the warm ocean. To the westward, for instance, of the Sierra Nevadas on the annual map there is a rainfall of from 20 to 40 inches. Immediately to the eastward of this series of mountains the annual rainfall is only from 2 to 6 inches. Much the same is true of the Cascade Range, and even the Coast Range has

* "As a result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain-slopes, etc., are either inoperative or relatively insignificant." (*Nature*, XXXIX. 583.)

† Report of the Chief of the U. S. Weather Bureau for 1891 and 1892.

RAINFALL AND SNOW OF THE UNITED STATES.

Annual and seasonal averages, seasonal variation and cubic miles for each State.

State.	Area in Square Miles.	Spring.	Summer.	Autumn.	Winter.	Annual.	Seasonal Variation.	Cubic Miles.
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
Alabama	52,250	14.9	13.8	10.0	14.9	53.6	1.5	44.2
Arizona	113,020	1.3	4.3	2.2	3.1	10.9	3.3	19.4
Arkansas	53,850	14.3	12.5	11.0	12.8	50.6	3.9	42.5
California	158,360	6.2	0.3	3.5	11.9	21.9	40.0	54.9
Colorado	103,925	4.2	5.5	2.8	2.3	14.8	2.4	24.2
Connecticut	4,990	11.1	12.5	11.7	11.5	46.8	1.1	3.6
Delaware	2,050	10.2	11.0	10.0	9.6	40.8	1.1	1.3
District of Columbia	70	11.0	12.4	9.4	9.0	41.8	1.4	0.04
Florida	58,680	10.2	21.4	14.2	9.1	54.9	2.4	51.0
Georgia	59,475	12.4	15.6	10.7	12.7	51.4	1.5	48.2
Idaho	84,800	4.4	2.1	3.6	7.0	17.1	3.3	22.7
Illinois	56,650	10.2	11.2	9.0	7.7	38.1	1.5	34.0
Indiana	36,350	11.0	11.7	9.7	10.3	42.7	1.2	24.2
Indian Territory	31,400	10.6	11.0	8.9	5.7	36.2	1.9	17.7
Iowa	56,025	8.3	12.4	8.1	4.1	32.9	3.0	28.8
Kansas	82,080	8.9	11.9	6.7	3.5	31.0	3.4	40.0
Kentucky	40,400	12.4	12.5	9.7	11.8	46.4	1.3	29.3
Louisiana	48,720	13.7	15.0	10.8	14.4	53.9	1.4	41.6
Maine	33,040	11.1	10.5	12.3	11.1	45.0	1.2	23.2
Maryland	12,210	11.4	12.4	10.7	9.5	44.0	1.3	8.3
Massachusetts	8,315	11.6	11.4	11.9	11.7	46.6	1.0	5.9
Michigan	58,915	7.9	9.7	9.2	7.0	33.8	1.4	31.3
Minnesota	83,365	6.5	10.8	5.8	3.1	26.2	3.5	34.4
Mississippi	46,810	14.9	12.6	10.1	15.4	53.0	1.5	38.8
Missouri	69,415	10.0	12.4	9.1	6.5	38.0	1.9	41.2
Montana	146,080	4.2	4.9	2.6	2.3	14.0	2.1	32.1
Nebraska	77,510	8.9	10.9	4.9	2.2	26.9	5.0	32.9
Nevada	110,700	2.3	0.8	1.3	3.2	7.6	4.0	14.4
New Hampshire	9,305	9.8	12.2	11.4	10.7	44.1	1.2	6.3
New Jersey	7,815	11.7	13.3	11.2	11.1	47.3	1.2	5.6
New Mexico	122,580	1.4	5.8	3.5	2.0	12.7	4.1	24.5
New York	49,170	8.5	10.4	9.7	7.9	36.5	1.3	28.3
North Carolina	52,250	12.9	16.6	12.0	12.2	53.7	1.4	44.2
North Dakota	70,795	4.6	8.0	2.8	1.7	17.1	4.7	19.1
Ohio	41,060	10.0	11.9	9.0	9.1	40.0	1.3	25.7
Oregon	96,030	9.8	2.7	10.5	21.0	44.0	7.8	66.7
Pennsylvania	45,215	10.3	12.7	10.0	9.5	42.5	1.3	30.2
Rhode Island	1,250	11.9	10.7	11.7	12.4	46.7	1.2	0.8
South Carolina	30,570	9.8	16.2	9.7	9.7	45.4	1.7	21.6
South Dakota	77,650	7.2	9.7	3.5	2.5	22.9	3.9	28.1
Tennessee	42,050	13.5	12.5	10.2	14.5	50.7	1.4	33.4
Texas	265,780	8.1	8.6	7.6	6.0	30.3	1.4	127.0
Utah	84,970	3.4	1.5	2.2	3.5	10.6	2.3	14.3
Vermont	9,565	9.2	12.2	11.4	9.3	42.1	1.3	6.1
Virginia	42,450	10.9	12.5	9.5	9.7	42.6	1.3	28.5
Washington	69,180	8.6	3.9	10.5	16.8	39.8	4.3	43.4
West Virginia	24,780	10.9	12.9	9.0	10.0	42.8	1.4	16.6
Wisconsin	56,040	7.8	11.6	7.8	5.2	32.5	2.2	28.7
Wyoming	97,890	4.3	3.5	2.2	1.6	11.6	2.7	17.9
Total	2,985,850	....	....	....	....	....	....	1407.14
Average	....	9.2	10.3	8.3	8.6	36.3	3.0	......

a very marked influence on the rainfall. The annual line, for instance, of 40 inches of rainfall passes down the coast from Vancouver Island almost parallel to and westward of the Coast Range, although for most of this distance these mountains are quite low.

"Another curious fact which may be mentioned in connection with the general rainfall of the United States is that, generally, the great swampy areas occur in regions of highest rainfall. This is true, for instance, of the everglades of Florida, where the rainfall is from 50 to 70 inches per year. It is also true of the great swampy district lying on the coast of North Carolina, where the rainfall is 60 inches per year, and upward; also of the swampy district about the mouth of the Mississippi River; but is not so true of the celebrated swampy district lying to the west of the Mississippi along the Gulf coast.

"It is interesting to notice the effects of the Great Lakes on the rainfall visible on most of the maps. In general, it will be found that the rainfall is greater on the east shore of Lake Michigan than on the west shore. It is to be noted that the prevailing winds here reach the lake from the west. Either they gather up considerable moisture from the lakes which is deposited on the east shore, or, what is more probable, the temperature of the lake is such as to chill the air and cause it to deposit more of its moisture on the east shore than on the west. Much the same is true of the east shores of Lake Erie and Lake Ontario, areas which are small in both cases, because the lakes themselves lie east and west. There is, however, a distinct increase of rainfall along the southeastern coast of Lake Erie and to the east of Lake Ontario. These features can be traced on the monthly maps, but more perfectly on the seasonal ones. The effect seems to be somewhat more marked in the cold seasons than in the warm, and it is a noteworthy fact that

the areas of deep snows in Michigan and New York are found to be on the same line. The area of deep snows for Southern Michigan is from the middle of the west coast, in the vicinity of Manistee, nearly straight across the peninsula; the area of deep snowfall in New York is to the eastward of Lake Ontario, and, to some degree, to the southward, in the immediate vicinity of the lake. It should also be noted that the area for deepest snow in the United States not mountainous is along the south shore of Lake Superior, from Marquette eastward. This would quite agree with the suggested influence of the lakes, in that the air passing over Lake Superior comes largely from the northwest, and by the time it reaches the coast in question has already received a surcharge of vapor chilled by the surface of this lake.

"Another interesting point is the average rainfall for the entire United States. The average of all stations, by States, gives for spring 9.2 inches, for summer 10.3 inches, for autumn 8.3 inches, and for winter 8.6 inches, and a total for the year of about 36 inches. It appears that the rainfall over the United States generally is quite evenly distributed through the year, varying in total amount for the seasons from 10.3 for summer to 8.3 for autumn. The spring and summer rainfalls are the highest; other things being equal the rainfalls of spring and, next to that, of summer are the most useful for agricultural operations.

"With the depth given it is not difficult to get the average total rainfall for the entire United States (excluding Alaska, where we have not sufficient information). For this purpose we may take the average for each State and multiply it by the area of the State, including water-surfaces. Adding these together we get 1407 cubic miles as the average annual total of water which descends as rain or snow in the United States. The figures for the areas are taken from

the census of 1890. The annual depth of rainfall which this gives is 29 inches, or less than that given by the other method. This is to be expected, as the other method gave equal weight to each political division, and these divisions are generally smaller in the regions of greater rainfall.

"To get some conception of this enormous mass of water we may compare it with the contents of the Great Lakes, and an approximate comparison is near enough. Lake Ontario is about 200 miles long and 70 broad, and its average depth is about 40 fathoms. It therefore contains about 636 cubic miles of water. The annual rainfall would fill it two times and leave something over for a third time. Lake Michigan is about 310 by 70 miles and has an average depth of about 50 fathoms, and consequently contains about 1233 cubic miles of water. The average annual rainfall would fill Lake Michigan and leave 174 cubic miles over. Four years of rainfall would probably be enough to fill all the Great Lakes." (U. S. Weather Report.)

Reports published upon State authority at times do not agree with the United States returns above given. Thus the Weather Bureau of the State of New York places the average annual rainfall for that State at 37.50 inches.

The average annual rainfall for Massachusetts, as deduced from long-continued observations, is given by the State Board of Health as 45.15 inches.

Data for Connecticut, as published by its Board of Health, being averages for twenty years (1873–92), are:

January	4.39 inches
February	4.16 "
March	4.66 "
April	3.56 "
May	3.54 "
June	3.15 "
July	5.27 "

August	5.36	inches.
September	3.79	"
October	3.95	"
November	3.95	"
December	3.52	"
	49.30	inches

with a maximum of 60.26 inches in 1888, and a minimum of 37.78 inches in 1892.

Some observations were carried on at the weather station in Philadelphia in 1892 with a view to determine the effect, if any, of placing the rain-gauge at different elevations above the surface of the ground:

TABLE SHOWING OBSERVATIONS ON RAINFALL AT DIFFERENT ELEVATIONS ABOVE THE SURFACE OF THE GROUND.

Month.	Elevation Above the Ground in Feet.					
	0	5	10	15	25	50
January	4.44	3.71	3.62	3.57	3.62	3.54
February	1.04	0.87	1.06	0.99	0.94	1.14
March	5.06	4.45	4.47	4.14	4.34	3.96
April	2.40	2.36	2.45	2.40	2.11	2.43
May	5.68	5.45	5.45	5.52	5.25	5.92
June	2.31	2.30	2.28	2.14	2.20	2.52
July	3.38	2.89	3.19	3.14	3.19	3.25
August	3.25	3.10	3.15	3.13	3.08	3.14
September	2.47	2.23	2.33	2.27	2.13	2.43
October	0.37	0.35	0.34	0.36	0.33	0.37
November	6.81	5.94	6.66	6.98	6.58	6.81
December	2.14	1.76	1.90	2.06	1.88	1.95
Totals	39.35	35.41	36.90	36.70	35.65	37.46

"The results further confirm those taken in 1891, and prove plainly that there is no material difference between 50 feet elevation and the surface of the ground.

"Discrepancies will be found in gauges placed in posi-

tions where surrounding objects produce counter-currents of air.

"The tabulated results have been compared with those obtained from the gauge on the ground and the automatic gauge. The variations are caused by the wind acting upon the mast."

SEVERE DROUGHTS IN THE MIDDLE STATES.*

"Mr. C. Warren furnishes the following from records giving the length of the most noted dry spells in the Middle States:

In the summer of 1634, 24 days.
In the summer of 1637, 74 days.
In the summer of 1642, 41 days.
In the summer of 1662, 80 days.
In the summer of 1664, 45 days.
In the summer of 1688, 81 days.
In the summer of 1694, 92 days.
In the summer of 1705, 30 days.
In the summer of 1715, 46 days.
In the summer of 1728, 61 days.
In the summer of 1730, 92 days.
In the summer of 1741, 72 days.
In the summer of 1745, 72 days.
In the summer of 1764, 108 days.
In the summer of 1755, 24 days.
In the summer of 1763, 133 days.
In the summer of 1773, 80 days.
In the summer of 1791, 82 days.
In the summer of 1812, 28 days.
In the summer of 1856, 26 days.
In the summer of 1871, 42 days.
In the summer of 1875, 26 days.
In the summer of 1876, 26 days.

"The longest drought above mentioned, which occurred in 1763, began on the first day of May, and many inhabitants of this country were compelled to send to Europe for grain and hay.

"These figures make Iowa's recent drought—the worst the State ever knew or is likely to know in the future—seem mild in comparison. June 22d there was a fall of rain in Marshall County of 1.25 inches and no more until July 20th, when there was another of a twenty-fifth of an inch, making

* Iowa Weather Service.

a dry spell of four weeks. So that our unprecedented drought is a mild one if it is to be compared with any one of dozens on record in the Eastern and Middle States.

"It should be noted that the longest period of drought in the above records occurred over a century ago, at which time but little progress had been made in clearing the vast forests, draining the ponds, tilling the fields, and making that section of the country habitable for civilized man. A careful study of records covering all the years since the early settlement of this country does not disclose any appreciable decrease or increase in the seasonal precipitation, or in the temperature and humidity of the air." *

Evaporation measurements, both for land- and water-surfaces, have been conducted very carefully at certain points of the United States, and the results have been recorded by such competent observers as Desmond FitzGerald, W. J. McAlpine,† Professor Fuertes, T. Russell, and others.

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* SOME HISTORIC DROUGHTS.—"There have been droughts in all ages and countries. In the year 310 A.D. hardly a drop of water fell in England, and 40,000 people died of famine.

"The seven years of drought and famine in Egypt, recorded in Genesis, began in the year 1708 B.C.

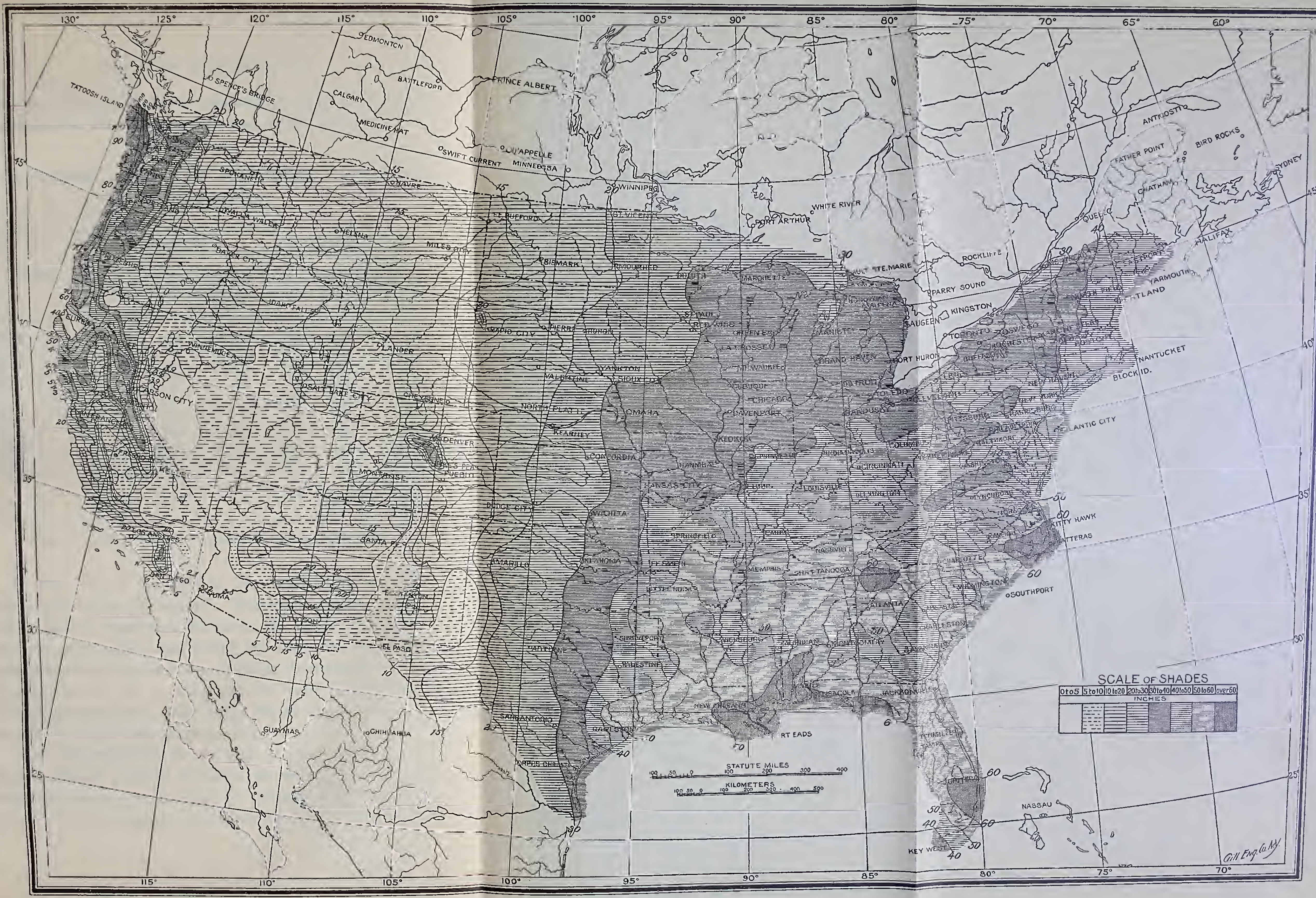
"In 954 a drought began in Europe lasting four years. The summers were intensely hot and the famine prevailed everywhere; 3,000,000 died of hunger.

"In 1771 an unprecedented drought prevailed throughout India. Scarcely any rain fell for a year, and hundreds of thousands died of famine, whole districts being depopulated.

"In 1837 drought and intensely hot weather prevailed in Northwest India. Over 800,000 persons perished from famine. Similar destruction was wrought by the same causes in 1865 and 1866, over 2,000,000 persons perishing of hunger in the two years."

† Wm. J. McAlpine, in a report to the Water Committee of Brooklyn in 1852, finds "that from 30 to 40 per cent of the falling rain and snow is carried off by evaporation." The experiments were made by himself. In the same report the quotations are found as to the mean evaporation in inches at the following places:

Great Britain....................	32 inches per annum
Paris............................	38 " " "



SCALE OF SHADES
0 to 5
5 to 10
10 to 20
20 to 30
30 to 40
40 to 50
50 to 60
over 60
INCHES
STATUTE MILES
KILOMETERS
EDMONTON
BATTLEFORD
PRINCE ALBERT
CALGARY
MEDICINE HAT
SPENCE'S BRIDGE
TATOOSH ISLAND
SWIFT CURRENT
MINNEDOSA
QU'APPELLE
WINNIPEG
WHITE RIVER
PORT ARTHUR
SAULT STE. MARIE
ROCKLIFFE
PARRY SOUND
KINGSTON
TORONTO
OSWEGO
SAUGEEN
PORT HURON
ANTICOSTI
BIRD ROCKS
FATHER POINT
CHATHAM
SYDNEY
HALIFAX
YARMOUTH
PORTLAND
EASTPORT
NANTUCKET
BLOCK ID.
ATLANTIC CITY
KITTY HAWK
HATTERAS
SOUTHPORT
WILMINGTON
CHARLOTTE
CHARLESTON
SAVANNAH
JACKSONVILLE
KEY WEST
NASSAU
SPOKANE
WALLA WALLA
HELENA
HAVRE
BAKER CITY
MILES CITY
BISMARCK
MOORHEAD
DULUTH
MARQUETTE
ST. PAUL
RED WING
LA CROSSE
MILWAUKEE
GRAND HAVEN
DUBUQUE
CHICAGO
DAVENPORT
KEOKUK
DETROIT
TOLEDO
SANDUSKY
CLEVELAND
BUFFALO
ROCHESTER
PITTSBURG
NEW YORK
NEW HAVEN
BOSTON
IDAHO FALLS
LANDER
RAPID CITY
PIERRE
HURON
YANKTON
SIOUX CITY
VALENTINE
NORTH PLATTE
OMAHA
KEARNEY
CONCORDIA
HANNIBAL
KANSAS CITY
ST. LOUIS
CINCINNATI
LOUISVILLE
LEXINGTON
LYNCHBURG
WASHINGTON
BALTIMORE
PHILADELPHIA
COLUMBUS
WINNEMUCCA
CARSON CITY
SALT LAKE CITY
CHEYENNE
DENVER
PIKES PEAK
PUEBLO
MONTROSE
DODGE CITY
WICHITA
SPRINGFIELD
CAIRO
NASHVILLE
MEMPHIS
CHATTANOOGA
ATLANTA
AUGUSTA
MONTGOMERY
MERIDIAN
VICKSBURG
SHREVEPORT
PALESTINE
LITTLE ROCK
FT. SMITH
OKLAHOMA
AMARILLO
ABILENE
SANTA FE
EL PASO
TUCSON
YUMA
SAN DIEGO
LOS ANGELES
FRESNO
KEELER
SAN FRANCISCO
EUREKA
ROSEBURG
PORTLAND
SAN ANTONIO
CORPUS CHRISTI
GALVESTON
NEW ORLEANS
PENSACOLA
PT. EADS
TAMPA
TITUSVILLE
GUAYMAS
CHIHUAHUA
Gill Eng. Co. N.Y.

From the reports of these gentlemen, and from other official sources, the following data have been drawn:

TABLE SHOWING RELATION OF EVAPORATION TO RAINFALL (MASSACHUSETTS).

Month.	Average Year.			Year of Low Rainfall (1883).		
	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.	Rainfall, Inches.	Evaporation, Inches.	Excess or Deficiency of Rainfall, Inches.
January	4.18	0.98	+ 3.20	2.81	0.98	+ 1.83
February	4.06	1.01	+ 3.05	3.86	1.01	+ 2.85
March	4.58	1.45	+ 3.13	1.78	1.45	+ 0 33
April	3.32	2.39	+ 0.93	1.85	2.39	— 0.54
May	3.20	3.82	— 0.62	4.18	3.82	+ 0.36
June	2.99	5.34	— 2.35	2.40	5.34	— 2.94
July	3.78	6.21	— 2.43	2.68	6.21	— 3.53
August	4.23	5.97	— 1.74	0.74	5.97	— 5.23
September	3.23	4.86	— 1.63	1.52	4.86	— 3.34
October	4.41	3.47	+ 0.94	5.60	3.47	+ 2.13
November	4.11	2.24	+ 1.87	1.81	2.24	— 0.43
December	3.71	1.38	+ 2.33	3.55	1.38	+ 2.17
	45.80	39.12	+ 6.68	32.78	39.12	— 6.34

NOTE.— + indicates excess of rainfall; — indicates deficiency.

In the year of low rainfall the evaporation was 6.34 inches greater than the rainfall. During the warmer months, from April to September inclusive, the excess of evaporation was 15.22 inches, and during the other six months the rainfall was 8.88 inches in excess of the evaporation. These figures indicate that a pond will not lower by evaporation in a dry summer more than about fifteen inches, even if it receives no water from its watershed.

Just determination of the rate of evaporation is a decidedly difficult problem to solve, for there exist so many disturbing factors which must be taken into the consideration—such as direction and force of wind, character of

soil, influence of crops, and such like matters—all of which tend to make the final result one of only very local application.

At Rothamsted, England, with an average annual rainfall of 31.04 inches, it was found that evaporation from bare soil amounted to 17.09 inches, and that 13.95 inches percolated to a depth exceeding five feet, and appeared as drainage. Of these 13.95 inches of drainage 9.44 inches collected during five months, beginning in October, and the remaining seven months furnished only 4.51 inches, showing that the ground-water depends upon winter drainage for its principal reinforcement.*

"Evaporation from saturated woodland soil is from 61 to 63 per cent less than from saturated soil in the open, the rainfall in woodland commonly exceeding the evaporation, even in summer.

"Woldrich found that less water percolated in soil upon which grass was growing than upon a bare soil. Very light rains were wholly lost by evaporation from the grass. He also noted that when the snow melted in the spring the water from it passed from it into the bare land quicker, and in larger quantity, than it did into the soil that was grass-covered.

"According to Wollny, a calcareous loam which permitted 38 per cent of the rainfall to soak through when it was bare of vegetation percolated no more than 20 per cent of the rainfall when grass or clover was growing upon it.

"After extensive investigation it has been established that the rain which falls upon a crop during its growth is insufficient for its maintenance, and that such a crop would die were it cut off from drawing upon the reserve water stored up in the ground.

* *J. Chem. Soc.* LI. 504.

"About one quarter of a summer rainfall may cling to the leaves of trees and evaporate directly therefrom, while at the same time the trees act as pumping-engines to dry the ground, owing to evaporation from their enormous leaf-surface. Thus clay lands often become very wet after the cutting off of the trees." (Storer.)

Johnson shows that filtration or percolation of water through two feet of soil in drain-gauges amounts to, in general, from 5 to 10 inches annually with a rainfall of from 26 to 44 inches.

The following is Risler's table of daily consumption of water for different crops, quoted in an article on irrigation by W. Tweeddale:*

	Inches.
Lucern grass	from 0.134 to 0.267
Meadow grass	from 0.122 to 0.287
Oats	from 0.140 to 0.193
Indian corn	from 0.110 to 1.570
Clover	from 0.140 to ....
Vineyard	from 0.035 to 0.031
Wheat	from 0.106 to 0.110
Rye	from 0.091 to ....
Potatoes	from 0.038 to 0.055
Oak-trees	from 0.038 to 0.030
Fir-trees	from 0.020 to 0.043

Mr. Tweeddale concludes that "from seed-time to harvest cereals will take up fifteen inches of water and grasses thirty-seven inches. These conclusions agree with practice in irrigation, and show plainly that the demands of plant-growth cannot be ignored in tracing the disappearance of rain. The figures also explain the low summer flow of streams flowing from a highly cultivated watershed. They

* Kansas State Board of Agriculture Report, December 31, 1889.

do not necessarily explain the effect of forests in regulating flow, since many watersheds, although cleared of trees, are not put under cultivation, but still show some change in flow. The action of forests is probably largely to retard surface-flow by means of irregular surfaces, caused by roots, fallen timber, absorbent mosses, and leaf accumulation, thus holding the water until it can be taken into the ground. This is not mere theory; it is based on observations made during many days spent in the forest, and is believed to almost, if not fully, account for the better sustained flow of forest streams and their lighter flood-flows."

The official figures of the United States Weather Service will be found on the following four pages.

"The daily evaporation from the surface of the United States has been generally assumed by engineers to be about 0.4 in. in 24 hours. But experiments prove that this may be doubled under certain conditions of dryness, temperature, and pressure; and at other times the evaporation may be negative; that is, moisture is actually added to the contents of the evaporation-gauge. What the resultant effect of these changes is no one can at present foresee; for the question has not been properly studied before for utilitarian purposes." (Fuertes.)

The flow of streams depends upon causes quite various in character, such as deep-seated springs, melting of glaciers (e.g., the River Rhone), and other like unusual sources, but for the great majority of cases the flow is traceable directly to the rainfall and to springs of local origin.

What is the amount of the "run-off" to be expected per square mile of watershed is essentially an engineering question, not to be considered here beyond stating the views of some prominent authorities.

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL SERVICE STATIONS, IN THERMOMETER SHELTERS,

computed from the means of the tri-daily determinations of dew-point and wet-bulb observations.

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888	May, 1888.	June, 1888.	July, 1887.	Aug. 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
New England.													
Eastport........	0.9	1.4	1.5	2.4	2.5	2.7	2.2	2.9	2.5	2.6	2.2	1.4	25.2
Portland..........	1.0	1.2	1.8	2.6	1.8	3.3	3.8	3.9	3.4	3.0	2.5	1.4	29.7
Manchester........	0.9	1.6	2.2	3.3	3.8	5.0	4.1	3.3	2.5	2.8	2.4	1.4	33.3
Northfield.........	0.8	1.0	1.5	2.3	2.5	3.4	3.5	2.7	2.3	1.8	1.1	1.0	23.9
Boston............	1.2	1.6	2.2	3.4	3.1	4.7	4.4	4.0	3.5	2.7	2.2	1.4	34.4
Nantucket.........	1.1	1.1	1.2	1.5	1.8	2.1	3.3	3.8	3.4	2.7	1.8	1.8	25.6
Wood's Holl......	0.5	0.8	1.8	2.4	1.8	2.7	2.7	2.4	2.7	1.2	0.8	0.5	20.3
Block Island.......	1.1	1.1	1.2	2.0	1.8	2.6	2.5	3.1	2.8	2.6	1.8	1.4	24.0
New Haven.......	1.1	1.6	1.8	2.7	2.7	4.1	3.7	3.8	3.1	3.2	2.4	1.6	31.8
New London......	1.5	1.3	1.5	2.6	2.8	4.0	3.4	3.9	3.2	3.1	2.4	2.1	31.8
Mid. Atlantic States.													
Albany......	0.9	1.2	1.6	3.3	3.9	4.5	5.0	4.7	3.2	3.0	2.1	1.4	34.8
New York City....	1.8	1.4	2.0	3.4	3.3	4.6	5.0	5.2	4.3	4.1	3.3	2.2	40.6
Philadelphia.......	1.6	2.1	2.5	4.4	4.0	5.7	5.7	5.2	4.3	4.0	3.3	2.2	45.0
Atlantic City	1.2	1.6	1.5	2.4	1.8	3.6	2.9	3.3	2.4	1.8	1.2	1.5	25.2
Baltimore..... ..	2.0	2.2	2.8	5.1	4.7	5.6	6.0	5.0	4.4	4.3	3.6	2.4	48.1
Washington City...	1.8	1.7	2.5	4.2	3.8	6.0	5.4	4.9	4.1	4.2	4.5	2.5	45.6
Lynchburg........	2.6	2.7	3.4	5.2	4.5	5.6	4.7	4.3	3.3	3.4	3.2	2.6	45.5
Norfolk...........	1.8	1.6	2.3	3.5	3.2	4.2	4.6	3.7	3.7	2.9	2.3	1.8	35.6
So. Atlantic States.													
Charlotte..........	2.6	2.6	4.3	6.4	4.5	5.8	4.0	4.0	4.6	4.0	3.6	2.6	49.0
Hatteras	1.8	1.6	1.6	2.5	2.2	3.0	3.3	4.1	3.8	3.2	2.6	1.6	31.3
Raleigh...........	2.0	1.8	2.6	3.8	4.1	5.4	4.2	3.2	3.0	2.7	2.4	1.8	37.0
Wilmington.......	2.4	2.2	2.7	3.3	3.3	4.3	4.3	3.1	3.9	3.4	2.8	2.7	38.4
Charleston	2.5	2.5	3.5	3.7	3.9	4.4	4.5	4.8	4.2	4.0	3.2	2.5	43.7
Columbia..........	2.2	2.3	2.6	4.8	4.3	5.4	4.2	3.8	4.2	3.4	3.6	2.4	43.2
Augusta...........	3.0	2.6	3.4	5.3	4.8	5.0	4.8	4.5	5.1	4.1	3.6	3.1	49.3
Savannah	3.3	2.8	4.1	4.7	4.3	4.6	4.2	4.7	3.4	3.6	3.5	2.8	46.0
Jacksonville.......	2.9	2.6	3.8	4.3	4.6	5.3	5.0	4.7	3.8	3.6	3.0	2.1	45.7
Florida Peninsula.													
Titusville..........	3.5	2.6	3.3	3.8	3.8	4.3	3.8	4.3	4.0	4.1	3.6	3.1	44.2
Cedar Keys........	3.3	2.8	4.0	4.6	4.5	5.1	5.0	5.5	4.5	4.1	3.5	2.6	49.5
Key West.........	3.8	3.7	3.8	4.5	4.4	4.8	5.1	5.1	4.7	4.3	3.8	3.6	51.6
Eastern Gulf States.													
Atlanta............	2.7	2.6	4.0	6.2	4.7	5.0	4.5	4.7	5.8	4.6	4.2	2.5	51.5
Pensacola.........	2.9	2.8	4.1	4.0	4.3	4.6	5.0	5.4	5.2	4.5	3.6	2.4	48.8
Mobile............	2.6	2.5	2.8	3.5	3.7	4.0	4.1	4.6	4.6	4.1	3.4	2.2	42.1
Montgomery.......	3.5	3.3	5.1	6.5	5.9	5.8	4.3	4.5	5.7	4.6	4.3	3.1	56.6
Vicksburg.........	2.1	2.5	3.6	5.1	5.7	4.8	4.0	5.0	4.7	3.4	4.0	2.2	47.1
New Orleans.......	2.8	2.8	4.1	3.8	4.2	4.1	4.1	4.3	4.4	4.6	3.7	2.5	45.4
Western Gulf States													
Shreveport.	1.6	2.1	3.0	4.8	4.9	4.2	4.9	5.2	5.0	4.1	3.4	2.4	45.6
Fort Smith........	2.2	2.7	3.5	5.3	4.4	4.6	5.6	4.6	4.7	5.9	3.9	2.2	49.6
Little Rock........	2.1	2.8	3.5	5.5	4.8	4.1	5.4	5.9	5.8	5.2	4.3	2.3	51.7
Corpus Christi.....	1.4	1.6	3.3	3.0	3.2	3.9	4.4	4.3	4.3	4.1	3.0	2.3	38.8
Galveston..... ..	1.6	2.8	3.2	2.9	4.3	4.2	5.3	5.2	5.2	4.7	4.2	2.4	46.0

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL SERVICE STATIONS, ETC.—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Western Gulf States.													
Palestine..........	2.1	3 0	3.3	4.2	4.3	4.5	5.8	4.6	4.8	4.4	4.0	2.1	47.1
San Antonio.......	2.4	3.3	4.1	3.8	4.0	4.5	6.6	5.8	5.2	5.4	4.2	3.1	52.4
Rio Grande Valley.													
Rio Grande City...	2.7	3.5	3.5	3 6	4.5	4.6	6.9	7.0	5.2	4.9	3.6	3.1	53.1
Brownsville.......	1.8	2.6	2.9	3.0	3.5	3.9	4.0	4.1	3.3	3.0	2.6	2.3	37.0
Ohio Val. & Tenn.													
Chattanooga	2.0	3.3	3.3	5.3	3.7	4.3	4.3	5.0	5.4	4.0	3.9	1.9	46.4
Knoxville.........	2.4	2.6	3.4	5.0	3.5	4.2	4.9	5.0	4.9	4.1	3.8	2.1	45.9
Memphis..........	2.1	2.3	3.1	5.9	5.3	4.8	4.9	5.4	5.5	4.2	4.1	2.4	50.0
Nashville.........	1.9	2 1	3.2	5.9	5.0	5.1	5.5	6.3	5.9	4.0	3.3	1.9	50.1
Louisville.........	1.7	2.1	2.8	5.6	5.4	5.8	6.8	7.4	6.4	4.9	3.8	2.1	54.8
Indianapolis.......	1.3	1.4	2.2	4.6	4.8	5.7	7.7	6.9	5.2	4.1	3.1	1.6	48.6
Cincinnati.........	1.8	1.8	2.6	4.9	5.2	6.4	6.5	6.6	6.1	4.7	3.3	2.1	52.0
Columbus.........	1.6	2.0	2.3	4.5	4.8	5.8	6.9	6.4	5.1	4.0	2.6	1.8	47.8
Pittsburg..........	1.4	1.9	2.2	3.8	4.2	5.4	6.6	5.6	4.9	3.4	2.8	2.3	44.5
Lower Lake Region.													
Buffalo........ ...	0.8	1.1	1.3	2.2	3.3	3.9	4.9	5.2	3.9	2.8	1.9	1.6	32.9
Oswego	0.6	1.0	1.1	2.2	2,8	3.8	3.9	4.0	3.6	2.7	2.2	1.0	28.9
Rochester.........	0.5	1.1	0.9	2.6	3.8	4.9	4.6	4.1	3.8	2.6	2.2	1.3	32.4
Erie..............	1.0	1.4	1.4	2.7	3.7	4.6	5.5	4.8	3.1	2.5	1.9	1.2	33.8
Cleveland.........	1.1	1.4	1.5	2.9	3.3	4.4	5.2	4.9	3.8	3.4	2.4	1.4	35.7
Sandusky	0.8	1.4	1.5	3.2	3.7	4.6	5 4	5.4	3.7	3.4	2.2	1.3	36.6
Toledo............	0.9	1.1	1.5	3.5	3.8	4.6	6.0	6.4	3.7	3.4	2.4	1.3	38.6
Detroit............	0.8	1.1	1.6	3.0	4.1	4.8	5.9	5.2	3.4	2.8	2.0	1.3	36.0
Upper Lake Region.													
Alpena	0.7	0.6	0.9	1.6	2.1	3.6	3.8	3.7	2.8	2.2	1.5	0.8	24.3
Grand Haven......	0.5	0.7	1.3	2.6	3.1	3.8	4.7	3.8	2.7	2.6	1.7	1.1	28.6
Lansing...........	0.6	1.2	1.4	2.7	2.8	4.0	4.3	3.9	2.4	1.9	1.4	1.0	27.6
Marquette.........	0.8	0.8	0.9	1.7	2.4	3.3	3.4	3.3	3.1	2.2	1.3	1.3	24.5
Port Huron........	0.6	1.0	1.1	2.6	3.0	3.8	4.6	4.2	3.2	2.5	1.7	1.0	29.3
Chicago...........	1.0	1.2	1.8	3.2	3.3	4.8	5.4	5.3	4.1	3.2	2.3	1.2	36.8
Milwaukee........	0.5	1.0	1.1	2.4	2.6	3.8	4.8	3.7	3.4	2.9	1.9	0.9	29.0
Green Bay........	0.5	0.6	0.8	1.7	2.5	4.1	5.6	4.2	3.0	2.4	1.9	0.9	28.2
Duluth............	0.5	0.5	0.6	1.5	2.4	2.5	3.9	3.4	3.0	2.5	1.2	1.0	23.0
Extreme Northwest.													
Moorhead.........	0.2	1.4	0.5	2.1	3.6	3 8	3.7	3.3	3.5	2.4	1.3	0.5	26.3
Saint Vincent......	0.3	0.3	0.5	1.8	3.8	3.9	3.1	2.6	2.6	2.0	0.9	0.3	22.1
Bismarck	0.4	0.6	0.6	3.0	4.3	4.1	5.6	4.2	4.0	2.6	1.2	0.4	31.0
Fort Buford	1.4	0.7	0.6	3.0	4.7	5.0	6.2	4.9	4.8	3.0	1.7	0.5	35.5
Fort Totten........	0.2	0.3	0.4	2.2	4.6	3.8	4.2	3.7	3.7	2.3	1.4	0.4	27.2
Up. Mississippi Val.													
Saint Paul...... ..	0.7	0.7	2.2	2.0	2.3	4.1	5.0	3.7	2.8	2.4	1.5	0.7	28.1
La Crosse.........	0.4	1.2	1.4	3 3	3.5	4.4	5.4	4.7	3.0	3.0	1.8	0.8	32.9
Davenport	0.5	1.0	1.8	3 8	3.4	4.6	6.9	6.2	4.4	3.0	2.3	1.1	39.0
Des Moines.......	0.6	1.0	1.5	3.7	3.1	4.2	6.6	4.7	4.1	3.3	2.3	0.9	36.0
Dubuque..........	0.7	1.0	1.4	2.2	2 9	4.2	6.2	4.8	3.3	2.8	1.8	0.9	33.2
Keokuk...........	0.8	1.1	2.1	4.2	3.7	4.3	7.0	6.8	5.0	3.8	2.9	1.2	42.9
Cairo	1.6	2.1	2.9	5.8	4.4	4.3	5.6	6.5	5.1	4.5	3.8	2.3	48.9
Springfield, Ill.....	0.8	1.1	2.0	4.6	3.8	4.3	5.4	6.5	4.5	3.5	2 9	1.4	40.8
Saint Louis........	1.3	1.6	2.5	5.5	4.7	5.0	7.5	8.0	5.9	4.9	3.9	1.4	52.2

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL SERVICE STATIONS, ETC.—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept. 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
Missouri Valley.													
Lamar	1.1	1.6	2.4	4.4	3.8	4.0	6.0	4.6	3 7	3.6	2.9	1.5	39.6
Springfield, Mo.	1.1	1.7	2.4	5.0	4.8	4.0	5.0	3.4	3.4	3.5	3.1	1.4	38.3
Leavenworth	0.9	1.5	2.3	4.6	4.5	5.0	6.3	4.5	4.0	3.9	2.7	1.4	41.6
Topeka	1.1	1.2	2.0	4.0	4.1	4.1	6.3	3.5	3.2	3.0	2.2	1.4	36.1
Omaha	0.8	1.5	1.4	4.4	3.8	5.2	6.2	5.2	4.3	4.3	3.0	1.4	41.7
Crete	0.7	1.1	1.2	3.5	3.3	4.5	5.6	4.7	3.8	3.6	2.4	1.1	35.5
Valentine	1.2	1.6	1.8	5.0	3.2	5.3	6.9	5.0	5.2	3.8	3.3	1.5	43.8
Fort Sully	0.6	0.9	1.3	4.4	4.1	5.2	7.7	4.9	5.7	3.6	2.8	0.7	41.9
Huron	0.3	0.7	0.8	3.7	3.7	4.1	5.7	4.2	4.1	3.1	2.4	0.7	33.0
Yankton	0.4	1.4	1.2	3.3	3.1	4.4	4.6	3.7	2.9	3.0	2.2	0.8	31.0
Northern Slope.													
Fort Assiniboine	0.8	1.2	1.2	3.8	4.1	4.2	6.8	5.5	4.8	3.5	2.5	1.1	39.5
Fort Custer	0.6	1.5	1.3	5.4	6.8	4.9	9.6	8.0	6.1	3.4	2.9	1.5	52.0
Fort Maginnis	1.1	1.4	1.1	3.3	3.2	4.6	6.8	4.6	3.8	2.8	2.0	1.1	35.8
Helena	1.1	3.6	2.1	6.1	4.3	5.5	7.2	7.7	6.4	4.3	3.0	2.1	53.4
Poplar River	0.4	0.8	0 8	2.7	4.9	5.7	6.0	4.8	4.4	2.5	1.7	0.7	35.4
Cheyenne	3.3	5.7	4.0	8.2	5.2	10.4	8.0	7.7	8.6	5.8	6.1	3.5	76.5
North Platte	0.8	1.8	1.8	5.4	3.9	6.9	6.0	4.8	3.7	2.8	2.3	1.1	41.3
Middle Slope.													
Colorado Springs	3.0	3.3	4.1	6.7	5.6	4.3	6.7	7.2	6.8	4.6	4.2	2.9	59 4
Denver	2.8	3.7	3.5	7.6	5.8	10.5	8.3	8.5	6.1	4.9	4.2	3.1	69.0
Pike's Peak	2.1	1.3	1.5	2.1	1.8	1.9	3.0	4.0	3.0	2.3	2.8	1.0	26.8
Concordia	1.3	2.8	1.8	4.8	4.3	5.7	7.3	5.2	4.3	4.5	3.4	1.8	47.2
Dodge City	1.4	2.4	2.8	4.1	4.6	7.4	8.3	6.6	5.5	5.2	4 2	2.1	54.6
Fort Elliott	1.3	1.9	3.2	5.1	5.4	8.2	7.6	6.2	5.4	4.7	4.2	2.2	55.4
Southern Slope.													
Fort Sill	1.6	2.0	2.6	3.8	4.0	4.4	4.8	7.5	5.1	4.2	4.1	2.0	46.1
Abilene	1.8	1.7	3.1	4.2	5.0	5.8	9.5	7.5	6.2	4.5	3.4	1.7	54.4
Fort Davis	5.4	5.7	6.7	8.5	11.0	12.0	11.4	9.0	5.9	5.2	5.7	4.9	96.4
Fort Stanton	3.9	3.9	5.2	7.3	9.5	10.9	9.4	11.6	3.9	4.0	3.6	3.8	76.0
Southern Plateau.													
El Paso	4.0	3.9	6.0	8.4	10.7	13.6	9.4	7.7	5.6	5.2	4.6	2.9	82.0
Santa Fé	3.0	3.4	4.2	6.8	8.8	12.9	9.2	9.8	6.6	6.7	5.7	2.7	79.8
Fort Apache	2.6	3.0	3 6	6.8	9.4	9 1	7.1	6.7	5.3	5.2	4.1	2.6	65.5
Fort Grant	5.2	4.8	6 4	9.2	10.2	13.8	12.4	10.5	9.0	7.9	7.2	4.6	101.2
Prescott	1.4	2.8	3.6	5.4	6.2	8.1	6.6	6.5	4.7	4.9	3.6	2.2	56.0
Yuma	4.4	5.2	6 6	9.6	9.6	12.6	11.0	10.2	8.2	8.2	5.5	4.6	95.7
Keeler	3.0	4.6	6.3	8.7	9.3	11.9	12.8	13.9	10.6	8.8	5.9	4.8	100.6
Middle Plateau.													
Fort Bidwell	0.8	1.8	1.8	4.6	5.2	4.0	8.8	8.1	5.0	4.6	2.4	1.3	48.9
Winnemucca	0.9	2.8	6.2	9.1	9.3	10.1	11.5	12.0	9.9	6.6	3.7	1.8	83.9
Salt Lake City	1.8	2.7	3.6	7.2	6.9	8.9	9.2	10.7	9.6	6.5	5.0	2.3	74.4
Montrose	1.8	2.7	3.7	6.2	7.0	11.1	10.2	8 3	6.9	5.2	3.4	2.0	68.3
Fort Bridger	1.6	2.5	2.7	4.3	4.3	6.5	7.7	6.8	5.6	4.2	5.2	4.7	56.1
Northern Plateau.													
Boisé City	1.6	2.5	3.8	6.1	6.5	6.6	10.0	9.2	7.4	5.2	3.2	1.8	63.9
Spokane Falls	0.7	1.7	2.7	4.4	5.4	4.4	7.7	6.4	3.8	2.5	1.7	1.4	42.8
Walla Walla	1.1	2.9	3.6	6.2	7.7	5.7	9.9	7.9	5.1	3.4	1.8	2.4	57.7
North Pacific Coast.													
Fort Canby	1.2	1.1	1.8	2.1	2.8	2.3	1.8	2.9	1.8	1.8	1.5	0.9	21.1

DEPTH OF EVAPORATION, IN INCHES, AT SIGNAL SERVICE STATIONS, ETC.—*Continued.*

Stations and Districts.	Jan., 1888.	Feb., 1888.	Mar., 1888.	April, 1888.	May, 1888.	June, 1888.	July, 1887.	Aug., 1887.	Sept., 1887.	Oct., 1887.	Nov., 1887.	Dec., 1887.	Year.
North Pacific Coast.													
Olympia..........	1.3	1.2	1.8	2.5	4.1	3.3	3.2	3.1	2.4	1.5	1.3	1.1	26.8
Port Angeles......	1.0	0.9	1.8	1.8	2.5	2.1	2.1	1.8	1.5	1.2	1.3	1.1	19.1
Tatoosh Island ...	1.2	1.1	1.8	1.4	1.8	1.8	1.4	1.4	1.4	1.6	1.8	1.4	18.1
Astoria............	1.1	1.0	1.6	2.1	3.0	2.7	3.0	2.9	2.6	2.3	1.8	1.2	25.3
Portland..........	0.9	1.1	2.4	3.4	5.0	3.2	5.4	4.2	3.4	2.7	1.8	1.2	34.7
Roseburg..........	1.2	1.6	2.7	3.9	4.7	3.5	5.4	4.7	5.0	3.2	1.7	1.6	39.2
Middle Pacific Coast													
Red Bluff.........	3.0	4.6	5.4	6.1	7.0	6.9	11.0	10.7	10.1	10.5	5.9	3.6	84.8
Sacramento.......	1.8	3.1	3.7	4.3	4.2	5.6	5.9	5.6	6.5	7.3	3.9	2.4	54.3
San Francisco.....	2.7	2.7	3.3	3.1	2.8	3.1	2.4	2.5	3.3	5.0	2.8	3.0	36.7
South Pacific Coast.													
Fresno............	1.8	2.8	3.0	5.6	6.0	7.0	9.1	10.2	7.6	6.7	3.8	2.2	65.8
Los Angeles.......	2.3	2.0	2.8	3.4	3.0	3.8	3.2	3.5	3.1	4.1	3.0	3.0	37.2
San Diego	2.9	2.7	2.5	2.7	3.3	2.8	3.2	3.3	2.9	4.3	3.2	3.7	37.5

Fanning believes that for ordinary watersheds it is fair to assume that 50 per cent of the annual rainfall flows off in the streams.*

More in detail, it is as follows:

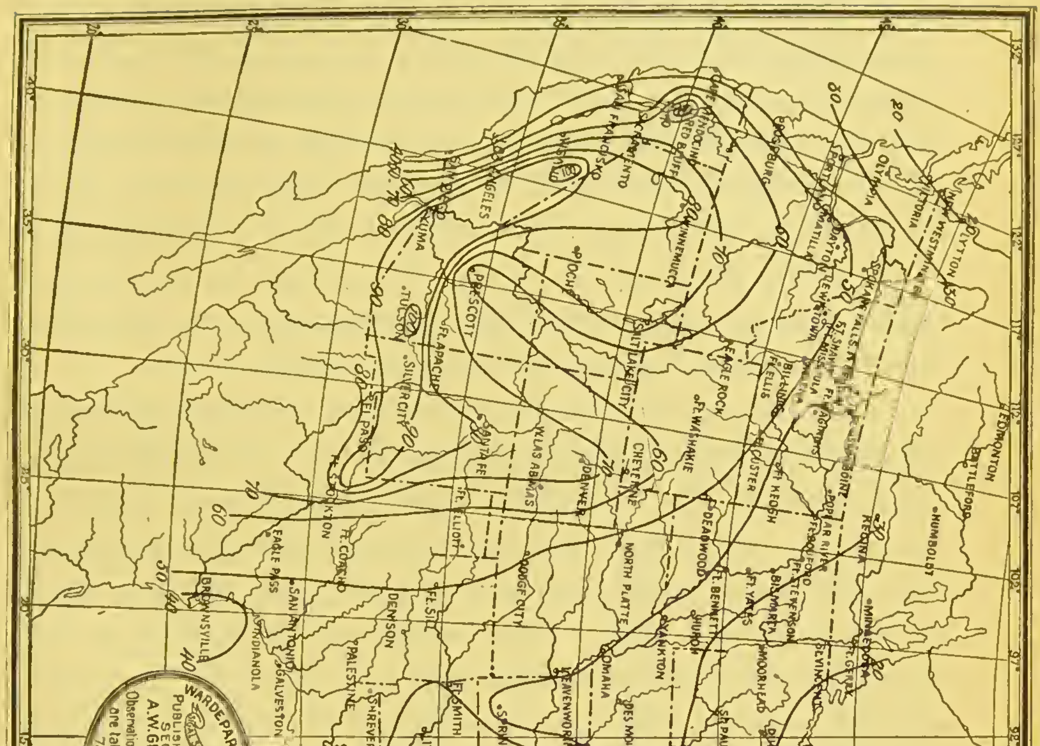
Mountain slope or steep rocky hills.........	80 to 90 per cent
Wooded swampy lands......................	60 " 80 " "
Undulating pasture and woodland..........	50 " 70 " "
Flat cultivated lands and prairie.............	45 " 60 " "

He also considers the "low rain cycles" mean rainfall to be about 80 per cent of the general mean rainfall.

According to the U. S. government reports, "for the area of the United States east of the ninety-fifth meridian

* An inch of rain amounts to 3630 cubic feet, or 27,155 U. S. gallons, or 101.3 tons per acre.

The weight of freshly fallen snow has been experimentally found to vary from five to twelve pounds per cubic foot. (Trautwine.)



LINES OF EQUAL ANNUAL DEPTH OF EVAPORATION, IN INCHES. BASED ON OBSERVATONS FROM JULY, 1887, TO JUNE, 1888, INCLUSIVE.

the run-off is from 35 to 50 per cent of the total rainfall. It appears to be largest in the vicinity of the Great Lakes, and diminishes from this region slowly to south and east, and rapidly towards the west. In the lower peninsula of Michigan, for instance, the run-off is 50 per cent of the total rainfall. Along the Gulf coast it appears to be only from 30 to 40 per cent, and along the Atlantic coast it probably varies from 30 to about 50 per cent. In general, for the interior States east of the ninety-fifth meridian the run-off is between 40 and 50 per cent of the total rainfall.

"As soon as we cross the ninety-fifth meridian westward we find a very sharp fall in the percentage of run-off to the total rainfall. For the band extending north and south between the ninety-fifth and one hundred and fifth meridians this percentage varies from 10 to 25 per cent, and over Iowa is about 33 per cent. The percentage is highest at the northern end of the band indicated, and lowest at the southern end. Going still farther westward we come to another very marked area, that of the Continental Divide; here the percentage of run-off suddenly increases, reaching the highest figure to be found in the United States. From Montana to Colorado it varies from 60 to 70 per cent of the total rainfall. In New Mexico it falls to about 33 per cent. This is evidently on account of the easy flow of water from the mountain ranges in the area in question. West of the Divide the run-off is again small, being only 15 or 20 per cent in Arizona and Nevada, about 30 per cent in Idaho, and nearly 50 per cent in Utah. Utah, it seems from its topography, partakes of the character of the band lying just to the east of it. Along the Pacific coast the run-off is about 25 per cent in Orgeon, 30 per cent in Washington, and between 45 and 50 per cent in California.

"In general, we may say that the run-off on the more level areas of the United States is less than 50 per cent,

and on the great plains may fall as low as 10 per cent. In the mountain regions it may rise to as high as 70 per cent. In the relatively dry areas, or the areas of distinctly dry seasons, the percentage is very much reduced." *

The following figures have been collected from various official sources, some of them having been prepared by C. C. Babb, of the U. S. Geological Survey:

RAINFALL AND RIVER-FLOW FOR THE CONNECTICUT RIVER BASIN, AVERAGES FOR 13 YEARS, 1871–85.

Month.	Average Rain in Inches.	River-flow in Inches on Whole Watershed.	Per Cent of River-flow to Rainfall.
January	3.27	1.93	59.1
February	3.10	2.04	65.8
March	3.94	3.00	76.3
April	3.26	4.73	145.0
May	3.17	4.19	132.2
June	4.00	1.46	36.5
July	4.79	1.02	21.3
August	4.87	1.06	21.8
September	3.04	0.89	29 3
October	3.93	1.11	28.3
November	3.93	1.76	44.8
December	3.39	2.06	60.7
	44.69	25.25	56.5

* "The point at which a region may be classed as arid and unfit for successful agriculture without irrigation should be lowered, it is believed, to 15 inches annual rainfall." (Report of Chief Signal Officer, 1889.)

RAINFALL AND RIVER-FLOW FOR SUDBURY RIVER (MASS.) WATERSHED, MEAN FOR 18 YEARS, 1875–92 INCLUSIVE.

Month.	Rainfall in Inches.	River-flow in Inches on Watershed.	Per Cent of River-flow to Rainfall.
January	4.430	2.307	52.08
February	4.076	3.223	79.07
March	4.055	5.097	109.49
April	3.214	3.533	109.93
May	3.269	1.957	59.87
June	3.016	0.853	28.28
July	3.788	0.335	8.84
August	4.266	0.534	12.52
September	3.163	0.450	14.23
October	4.200	0.938	22.33
November	4.144	1.537	37.09
December	3.565	1.833	51.42
	45.786	22.599	49.36

AVERAGES FOR THE SAVANNAH BASIN DURING 8 YEARS, 1884–92.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall.
January	4.34	2.50	57.6
February	3.47	2.59	74.6
March	4.86	3.13	64.4
April	2.08	1.99	95.7
May	4.05	1.51	37.3
June	4.44	1.41	31.8
July	6.46	1.47	22.8
August	4.59	1.96	42.7
September	3.70	1.73	46.8
October	3.03	1.26	41.6
November	1.68	1.33	79.1
December	2.71	1.31	48.1
	45.41	22.19	48.9

AVERAGES FOR THE POTOMAC BASIN DURING 6 YEARS, 1886–92.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River flow to Rainfall.
January	3.21	2.09	65.2
February	3.35	3.36	100.1
March	4.39	3.62	82.6
April	3.48	3.51	101.0
May	5.11	2.36	46.3
June	5.25	1.93	36.8
July	4.89	1.00	20.5
August	3.81	0.78	20.5
September	3.86	1.06	27.5
October	2.65	1.21	45.7
November	2.88	1.79	62.3
December	2.59	1.32	51.1
	45.47	24.03	53.0

AVERAGES FOR THE NESHAMINY (PA.) BASIN DURING 7 YEARS, 1884–91.

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall.
January	4.28	3.98	93.1
February	4.42	4.22	95.2
March	3.88	3.51	90.5
April	3.06	2.19	71.6
May	3.75	1.03	27.6
June	4.31	0.75	17.4
July	6.05	1.34	22.2
August	4.91	1.35	27.5
September	3.88	1.18	30.4
October	4.04	1.34	33.2
November	3.84	1.73	45.1
December	3.78	2.56	67.8
	50.20	25.18	50.1

AVERAGES FOR THE CROTON (N. Y.) BASIN DURING 14 YEARS. (BABB.)

Month.	Rainfall in Inches.	River-flow in Inches.	Per Cent of River-flow to Rainfall
January	3.65	2.12	58.2
February	3.30	2 47	74.9
March	4.36	3.80	89.6
April	3.64	3.51	96 5
May	3.28	2.44	74.4
June	3.66	1.06	29 0
July	3.92	0.60	15.3
August	3.76	1.05	28.0
September	4.00	0.93	23.3
October	4.00	1.01	25.3
November	3.98	1.33	33.4
December	3.53	2.04	57.8
	45.08	22.30	49.6

These figures for the Croton watershed are slightly different from those given by the N. Y. State Board of Health, which latter cover a period of 21 years, 1870–90 inclusive, and are as follows:

Average yearly rainfall	48.37	inches
Average yearly river-flow	24.52	"
Per cent of river-flow to rainfall	50.70	"

Even with uniformity in rainfall the rate of river-flow must vary, owing to such disturbing factors as frozen ground in winter and excessive evaporation in summer.

For Eastern Massachusetts Mr. Desmond FitzGerald places the months in order of dryness, averaging as follows:

1. July.	4. June.	7. May.	10. April.
2. September.	5. October.	8. December.	11. February.
3. August.	6. November.	9. January.	12. March.

showing the wettest months to be the first four in the year.

INFLUENCE OF FORESTS UPON WATER-SUPPLY.

The following is freely condensed and extracted from the government report upon "Forest Influences," issued by B. E. Fernow, Chief of the Forestry Division.

The liability of forests to increase the actual annual precipitation is yet in discussion, but numerous data are available, tending to show that such increase occurs.

Field Station.			Compared with Average over Open Regions.		
Name.	Elevation.	Mean Annual Precipitation.	Name.	Mean Annual Precipitation.	Surplus over Woods.
	Feet.	Inches.		Inches.	Inches.
Schoo	10	28.4	North Sea coast	27.5	+ 0.5
Eberswalde	77	21.9	Brandenburg	21.8	+ 0.1
Fritzen	98	25.6	East Prussia	24.1	+ 1.5
Hadersleben	112	30.1	Baltic coast	26.0	+ 4.1
Lintzel	312	23.3	Hanover	26.9	− 3.6
Kurwien	407	24.5	East Prussia	24.1	+ 0.4
Marienthal	469	22 5	Thüringen and Saxon provinces.	23.2	− 0.7
Hagenau	500	31.6	Alsace-Lorraine	30.4	+ 1.2
Neumath	1159	32.3	"	30.4	+ 1.9
Friedrichsrode	1158	26.5	Thüringen and Saxon provinces	23.2	+ 3.3
Lahnhof	1975	44.2	Westphalia	30 7	+14.5
Hollerath	2005	38.3	Rhine country	25.6	+12.7
Schneidefeld	2230	50.2	Thüringen and Saxon provinces.	23.2	+27.0
Carlsberg	2400	38.9	Silesian Mountains	27.2	+11.5
Sonnenberg	2549	55.5	Harz	36.4	+19.1
Melkerei	3071	69.9	Alsace-Lorraine	30.4	+39.5

It seems from this that where the results at the stations near forests are compared with the general results in the section of country in which the station is situated the forest station usually shows more rainfall. Lintzel is exceptional, because near young trees on an exposed moor.

There is one further case, which is quoted by Dr. Brandis, for India. In the part of the central provinces between the Nerbudda River and Nagpur and Rajpur, embracing a part of the Satpura range of mountains, much attention has been paid for several years to the care of the forests, and

specially to protection against forest fires. In consequence a large territory, with scattered tree growth or entirely treeless, has been covered with a dense growth of young trees. Over this region the rainfall has been as follows, at the stations named:

	1875 and Before.		1876 to 1885.	Per Cent of Increase.
	Years.	Mean Annual.		
		Inches.	Inches.	
Badnur	1867–1875	39.83	47.83	20
Chindwara	1865–1870	41.43	48.48	17
Seoni	1865–1870	52.07	54.76	5
Mandla	1867–1875	53.58	56.32	5
Burha	1867–1875	64.51	71.65	11
Bilaspur	1865–1875	41.85	54.81	21
Rajpur	1866–1875	51.59	54.41	5
Annual average		49.27	55.47	13

Finding the air strata above forest stations more moist and cooler, although only slightly so, than over field stations, we would infer that the tendency to condensation over wooded areas might be greater than over open fields. Experience and measurements seem to sustain this reasoning.

While the forest may not everywhere increase precipitation over its own area and near it, yet the presumption is that large systems of forest growth over extensive areas alternating with open fields may establish sufficient differences in temperature and moisture conditions and in air currents to modify the fall, if not in quantity, yet in timely and local distribution.

Altogether the question of appreciable forest influence upon precipitation must be considered as still unsolved, with some indications, however, of its existence under certain climatic and topographical conditions in the temperate zone, especially toward the end of winter and beginning of spring.

As one of the most striking examples of an increase of precipitation, seemingly due to forest planting, the experience at Lintzel, on the Lüneberg heath, may be recalled, where, with a definite increase in forest conditions over an area of 25 square miles, a regular definite increase in rainfall beyond that of neighboring stations to the extent of 22 per cent within six years was observed, and a change from a deficiency to a considerable excess over the rainfall of these other stations.

A very considerable part of the water falling as rain upon a forest is returned to the atmosphere by transpiration through the leaves. It must be remembered, however, that the smaller vegetables also pump water out of the soil in a similar fashion, often more rapidly, per acre, than the forest trees.

During the period of vegetation the following varieties transpired per pound dry weight of leaves:

	Pounds of Water.
Birch and linden	600–700
Ash	500–600
Beech	450–500
Maple	400–450
Oaks	200–300
Spruce and Scotch pine	50–70
Fir	30–40
Black pine	30–40

Conifers, as was stated, transpire one sixth to one tenth of the amount which is needed by deciduous trees.

The transpiration from leaves in full sunshine is decidedly greater than from leaves in the diffused daylight or darkness. The absolute amount of annual transpiration as observed in forests of mature oaks and beeches in Central Europe is about one quarter of the total annual precipitation.

Evaporation in the forest is naturally much less than in the open fields.

EVAPORATION IN WOODS IN PER CENT OF EVAPORATION IN THE OPEN.

	Dr. Ebermayer's Results.						German Observations.		
	Water-surface.		Bare Soil.		Soil under Forest Litter and within Forest.	Rainfall.	Water-surface.		Rainfall.
	Open.	Woods.	Open.	Woods.			Open.	Woods.	
April........	1	.45	1.15	.64	.27	1.75	1	.51	1.37
May.........	1	.43	.91	.37	.16	.68	1	.47	1.35
June.........	1	.36	1.07	.38	.14	1.46	1	.41	1.91
July..........	1	.35	.89	.34	.12	1.02	1	.38	2.33
August.......	1	.34	.87	.36	.11	1.00	1	.36	1.98
September....	1	.33	.92	.39	.11	.59	1	.35	2.54
October......	1	.41	1.26	.44	.18	3.45	1	.37	8.49
May–Sept....	1	.36	.93	.35	.13	.95	1	.39	2.02

The forest cover, and especially the litter of a well-kept forest, may decrease the amount of evaporation within the forest to nearly seven eighths of that in the open. The reason for this important influence of the forest is due not only to the impeded air circulation, but also to the temperature and moisture conditions of the forest air and forest soil.

The stations of Prussia allow the following average for evaporation, the amount evaporated in the open fallow field being called 100:

	Evaporated.	Retained More than in Open Fallow Field.
	Per Cent.	Per Cent.
Under beech growth.......	40.4	59.6
Under spruce growth......	45.3	54.7
Under pine growth........	41.8	58.2
From cultivated field	90.3	9.7

It is this protection against evaporation which gives to the forest its chief value as a guardian of water-supply. The forest floor, with its irregularities and its spongelike qualities, moreover, stops the rapid and ruinous draining of the surface, with attendant denuding of the land, and favors slow percolation through the soil and reinforcement of the springs.

The New York Forest Commission, speaking of floods in the Adirondack region and the influence of forests in relation to them, say:

"In the uplands of the preserve there are many densely wooded tracts adjacent to others from which the forests have been stripped. The residents agree that in the former floods are unknown, while in the latter they are a yearly occurrence. Their appearance was coincident with the disappearance of the woods. It was then noticed that the bridges, which for many years had sufficed to span the streams during heavy rains, were no longer safe, and new ones with longer spans became a necessity."

They refer also to the effect of the removal of the forests in the Adirondack watersheds upon the navigation of the canals of the State and the whole system of inland commerce. They say:

"With the clearing away of the forests and the burning of the forest floor came a failure of canal supply that necessitated the building of costly dams and reservoirs to replace the natural ones which the fire and axe had destroyed. The Mohawk River, which for years had fed the Erie Canal at Rome, failed to yield any longer a sufficient supply, whereupon the Black River was tapped at Forestport, and its whole volume at that point diverted southward to assist the Mohawk in its work."

Ex-Governor Davis, of Maine, gives the following statement in regard to the effect of forest removal on the flow of streams in a case with which he is well acquainted:

"The Kenduskeag River empties into the Penobscot at Bangor. The stream rises some 30 miles from its mouth, one branch in the town of Dexter, and another in the town of Corinna. I am told that fifty or sixty years ago there was a continuous flow of water the year round in this stream, and at the town of Kenduskeag, 12 miles northeast of Bangor, were situated large lumber-mills on both sides of the stream. The water-flow was sufficient to carry them the year round. But during the past half century the land along the shores of the stream has been cleared throughout the greater part of its course. The result is that we have heavy spring freshets, also heavy freshets in the fall, sometimes doing much damage. I recollect, a dozen years ago or more, when living in the town of Corinth, through which said stream flows, almost every bridge on the stream was carried away in the month of March. Now, after the spring freshet subsides, the water falls rapidly until it dwindles to a very small stream, not one half the amount flowing during the summer months that did fifty years ago."

In consequence of deforestation evaporation from the soil is augmented and accelerated, resulting in unfavorable conditions of soil humidity and affecting unfavorably the size and continuity of springs. The influence of forest cover upon the flow of springs is due to this reduced evaporation, as well as to the fact that by the protecting forest cover the soil is kept granular and allows more water to penetrate and percolate than would otherwise. In this connection, however, it is the condition of the forest floor that is of greatest importance. Where the litter and humus mould is burned up, as in many, if not most, of our mountain forests, this favorable influence is largely destroyed although the trees are still standing.

Snow is held longer in the forest and its melting is retarded, giving longer time for filtration into the ground,

which also, being frozen to lesser depth, is more apt to be open for subterranean drainage. Altogether forest conditions favor, in general, larger subterranean and less surface drainage, yet the moss or litter of the forest floor retains a large part of the precipitation and prevents its filtration to the soil, and thus may diminish the supply to springs. This is especially possible with small precipitations. Of copious rains and large amounts of snow-water quantities, greater or less, penetrate the soil, and according to its nature into lower strata and to springs. This drainage is facilitated not only by the numerous channels furnished by dead and living roots, but also by the influence of the forest cover in preserving the loose and porous structure of the soil.

Although the quantity of water offered for drainage on naked soil is larger, and although a large quantity is utilized by the trees in the process of growth, yet the influence of the soil cover in retarding evaporation is liable to offset this loss, as the soil cover is not itself dried out.

The surface drainage is retarded by the uneven forest floor more than by any other kind of soil cover. Small precipitations are apt to be prevented from running off superficially through absorption by the forest floor. In case of heavy rainfalls this mechanical retardation in connection with greater subterranean drainage may reduce the danger from freshets by preventing the rapid collection into runs.

The temporary retention of large amounts of water and eventual change into subterranean drainage which the well-kept forest floor produces, the consequent lengthening in the time of flow, and especially the prevention of accumulation and carrying of soil and detritus which are deposited in the river and change its bed, would at least tend to alleviate the dangers from abnormal floods and reduce the number and height of regular floods.

Having once carefully selected a watershed, it should be protected with the greatest care which science suggests, and with the utmost vigor which the law allows. Right here is the weakness shown by many of our city councils. The law is strong enough, and the municipal rights are plenty, but it is often very difficult to move the authorities to proper action. The most fruitful source of evil arises from the unquestioned right of a riparian landholder to "water his stock." The broad interpretation of this right can be carried to an absurd degree; for instance, the writer has seen the open channel-way connecting the storage- and distributing-reservoirs of a large city doing duty, at one point of its course, as a farm-yard drain, the cattle standing and defecating in the small stream at pleasure.

It may not be amiss to here point out that regulations for the protection of a watershed which do well enough during summer months may entirely fail of effectiveness after the ground becomes frozen. Drainage material which at one time could sink into the ground and become oxidized by infiltration would at other seasons flow down steep slopes over the frozen surface, or if itself arrested by frost would be at a later date washed into the stream by melting snows over the yet unthawed ground. Such cases of contamination are not rare, and are at times followed by most serious consequences, as was instanced by the outbreak of typhoid fever at Plymouth, Pa. It is useless to depend upon the purifying action of frost, for, as Prudden has shown, typhoid germs can withstand being frozen in solid ice during a period of over three months.

To repeat what we have already touched upon, the purifying action of filtration through common soil is another point frequently misunderstood, and yet of important bearing when considering the protection of a watershed. Such filtration is only effective when it is intermittent.

The nitrifying organism which accomplishes the oxidation of the objectionable sewage material can only operate in presence of atmospheric oxygen. A supply of air must be present in the pores of the soil or else purification ceases. After a "dose" of sewage has been applied to a soil a sufficient interval must elapse to permit the air to renew the exhausted oxygen; otherwise the slow-moving and continuous stream of filth must carry its objectionable properties to considerable distances.

How important, then, that every privy located within drainage distance of a source of water-supply should be built without a vault, and should have its cleanings removed at frequent intervals and applied to successive pieces of ground!

However desirable for the moment a river may be as a source of water-supply, it must not be forgotten that the conditions may change in the course of years with the growth of population up-stream, as has been already noted on another page. Objection was recently raised, by the writer to the future use of the unfiltered water of a large river, on the ground that pollution of the stream by sewage material is certainly on the increase, and that the introduction of sewerage systems in the towns above will, at no distant date, render the river-water very undesirable. A small mountain brook was recommended instead. The local critics objected by saying:

"The assumed pollution of the water of the river by human occupancy upon its banks above the intake, in the light of modern science, cannot possibly be so great as it must, from necessity, be in the case of the inland stream when the occupancy and volume of the latter are compared with those of the river. The flow of the river amounts to about ten thousand cubic feet per second, while that of the stream is not over seventy feet per second, so that the occupancy of three or four families upon the latter would afford

greater danger of pollution than all the occupancy upon the river above our intake, when calculated as to their relative proportion in value and numbers."

This point is not well taken, unless it be admitted that the three or four families on the stream chance to have their privies and drains empty directly into the brook without soil intervention, an arrangement which would, of course, be prevented by the city authorities. The sewerage system of a town does turn its contents directly into the river in a raw state and without any purification, such as obtains from intermittent soil filtration, as in the case of properly located and cared-for country privies. The river in question is a large one, but it is possible to seriously pollute it, and it would appear that the up-stream towns are making arrangements to do so by the establishment of sewerage systems.

CHAPTER VII.

STORED WATER.

NATURE provides enormous quantities of water stored up in lakes and ponds ready for human consumption, and man frequently supplements this by impounding surface and deep-seated waters in artificial basins when the natural reservoirs of the district are unavailable or are insufficient in size. Some sharp lines of difference must be drawn, however, between the waters classed under this general head.

Lakes of such great size as to be properly considered inland seas—the Great Lakes of North America, for instance—furnish water of very constant composition, free from the considerable vegetable contamination so frequently met with in small lakes and ponds. Large as these Great Lakes are, the influence of the sewage from cities upon their shores is nevertheless beginning to be seriously felt. The pollution of Lake Michigan by the sewage of Chicago is a widely known fact, and it is yet an open question whether the present intake, situated, as it is, four miles from shore, may not be shortly reached by the ever-swelling volume of the city's refuse. A smaller instance of the same kind is met with at Erie, Pa. That city takes its water from Lake Erie through an intake situated near the shore in a bay formed by a somewhat long peninsula. City sewage is felt at the intake, as is shown by a comparison of the water at that point with a sample taken from the open lake beyond the peninsula:

	Intake.	Open Lake.
Free ammonia	.10	.02
Albuminoid ammonia	.175	.135
"Required oxygen"	2.85	2.55
Nitrogen as nitrites	.001	trace
Nitrogen as nitrates	trace	trace

Cleveland, O., also takes water from Lake Erie, and the writer is informed that an oily taste is noticed, which can be accounted for only on the supposition that city sewage, containing refuse from the Standard Oil Works, finds its way as far as the intake.

Much opportunity is given in large lakes for sedimentation to come into full play, and settlement is, in consequence, a very great item in the process of the natural purification of their waters.*

Thus Dunant found 150,000 germs per c.c. in water from Lake Geneva taken near the shore, and only 38 per c.c. in a sample from the middle of the lake. Percy Frankland examined the waters of two inlets of Loch Lintrathen and found them to contain 1700 and 780 germs per c.c. respectively, while the outlet of the loch contained but 30 per c.c.

Saratoga Lake, which indirectly receives the sewage of Saratoga, is not by any means of large dimensions, yet Currier finds the following evidence of sedimentation:

Surface	56 germs per c.c.
13 feet below surface	54 " " "
32 " " "	163 " " "

In smaller lakes and ponds the influence of surrounding vegetation begins to be felt, often so seriously as to inter-

* Examinations of Lake Ontario water by the Toronto Water Board at points 2½ to 3 miles from shore, where the depths ranged from 75 to 182 feet, gave an average of 101 bacteria per c.c. During violent winter storms, with high seas, the number of bacteria per c.c. was very greatly increased.

fere with the use of their waters for potable purposes. For instance, sundry small lakes (averaging 160 acres in water-surface) have been found by the author to furnish waters of the following compositions in parts per million:

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	N as Nitrates.	N as Nitrites.	Total Residue.
a	.005	.420	2	0	0	52
b.............	.025	.800	3	0	.001	84
c.....	.066	.170	3	....	....	46

One of the above waters is from a shallow, lily-grown lake, and is liable to produce temporary diarrhœa in most people. Another comes from a lake so overcharged with vegetable organisms that when the water is "in blow" handfuls of small plants may be gathered from any portion of its surface.

Some very interesting observations have been recently made, chiefly by Dr. Drown, showing the influence of depth upon the character of water in lakes and storage-reservoirs.

He found that during the summer season, owing to the comparative lightness of the warmer water, no circulation takes place below a depth of twenty feet, that being the usual distance to which wind and wave agitation extends. Should the lake be protected from the wind, the aerated layer may extend temporarily only ten feet from the surface, and below this level the cold, stagnant water rests, until such time as the chilling of the upper layer increases its gravity to and beyond that of the lower layer upon which it floats.* When this point is reached, readjustment of relative position is immediately instituted, in accordance

* FitzGerald finds that Lake Cochituate, which has an area of 785 acres, is not affected by wind and wave action below twelve feet from the surface.

with the change in specific gravity, and the water of the lake "turns over."

The formation of this stagnant layer begins in April in this latitude, and circulation is partly re-established in October and completely so in November. With the advent of freezing weather a second period of stratification is inaugurated which continues until the surface thaws again in the spring. Vertical circulation then progresses until the warm sun of later April renders the surface-water so light as to float upon the colder layers beneath, when summer stagnation again begins.

Whenever the lower stagnant layer is brought in contact with decomposing organic matter, as is the case in reservoirs with bottoms from which the vegetation has not been removed, the dissolved oxygen present is quickly used up; quantities of extractive matters pass into solution and the water becomes foul in odor and dark in color.

The following analyses, published by the Massachusetts State Board of Health, show this diminution, and ultimate total exhaustion, of dissolved oxygen in the stagnant layer. The amount of oxygen present is expressed as percentages of the amount required to saturate the water at the temperature when collected.

DISSOLVED OXYGEN AT DIFFERENT DEPTHS.

JAMAICA POND, BOSTON, JULY 14, 1891.

Depth.	Temperature of Water, Deg. Fahr.	Per Cent of Oxygen.
Surface	75.4	100
10 ft. below surface	75	100
20 ft. " "	54	49
30 ft. " "	42.4	29.47
35 ft. " "	42	4.18
40 ft " "	42	0
47 ft. " "	41.3	0

LAKE COCHITUATE, BOSTON WATER-WORKS (AUG. 17, 1891).

Surface	74.7	79.15
10 ft. below surface	66.4	83.69
20 ft. " "	53.6	35.86
30 ft. " "	49.3	21.33
40 ft. " "	48.2	20.93
45 ft. " "	48.2	1.65
50 ft. " "	45.7	0
57 ft. " " (bottom)	44.8	0

Even though the bottom of a lake or reservoir be perfectly clean and sandy, the dissolved oxygen must surely diminish in the lower layers of water, for no water is without some oxidizable contents, but it will not be reduced to zero, nor will the water become damaged in quality.

Uniform experience goes to prove that good water may be preserved in properly constructed reservoirs without deterioration for indefinite lengths of time. It must be remembered, however, in this connection, that to keep a ground-water in good condition it is necessary to cover the reservoir. Such waters are usually charged with mineral matter suitable for plant-food, and the higher organisms will be very likely to grow therein unless light be excluded. Thus the great reservoirs supplying the spring-waters of Paris are kept entirely dark, with the best of results. Reservoirs used to store the filtered surface-waters of continental Europe, as, for example, those at Stuttgart, are likewise dark, for the same reason.

Algæ depend for their development upon material furnishing nitrogen. Water containing a moderate amount of this element washed from natural sources will maintain but a moderate growth of, such plant-life, but where nitrogen is present in great quantity as nitrates, as is often the case in

deep-seated waters, the development of algæ is commonly excessive during reservoir storage.*

Experience in Massachusetts, as elsewhere, indicates that storage of surface-waters in open reservoirs causes but little change in the character of such waters, and that what small change does take place is beneficial. The effect of the storage of ground-waters in such reservoirs is, however, quite strongly marked.

Commenting upon the following table, F. P. Stearns says:

"In interpreting these analyses it will not be far out of the way if we consider the nitrates as representing food; the suspended albuminoid ammonia, the algæ and other organisms, and the dissolved albuminoid ammonia, an extract of dead organisms, with, perhaps, in addition, the excreta of live ones."

CHANGES IN GROUND-WATER DURING OPEN STORAGE.
PARTS PER MILLION.

	Albuminoid Ammonia.		Nitrogen as Nitrates.
	Dissolved.	Suspended.	
Water entered reservoir May 22.....	.016	.000	.600
May 24.....	.054	.170	.450
May 29.....	.082	.406	.040
June 26.....	.128	.060	.030

That the stagnation of water in the lower levels of the reservoir is not in itself objectionable has been well shown by Dr. Drown in his study of reservoirs Nos. 3 and 4 of the Boston Water-works:

"Water in the stagnant layer does not become foul unless there is decomposable organic matter present. Thus

* In this connection see an excellent article by Rafter on "Fresh-water Algae and their Relation to Purity of Public Water-supplies," Am. Soc. C. E. XXI. 483.

in Basin 4 of the Boston Water-works, which was carefully prepared for the reception of the water by the removal of all soil and vegetable matter, and is supplied with a brown, swampy water from a watershed almost entirely free from population, the water is good at a depth of 40 feet, because the water contains very little organic matter with a tendency to decomposition.

RESERVOIR NO. 3, BOSTON WATER-WORKS (AUG. 20, 1891).

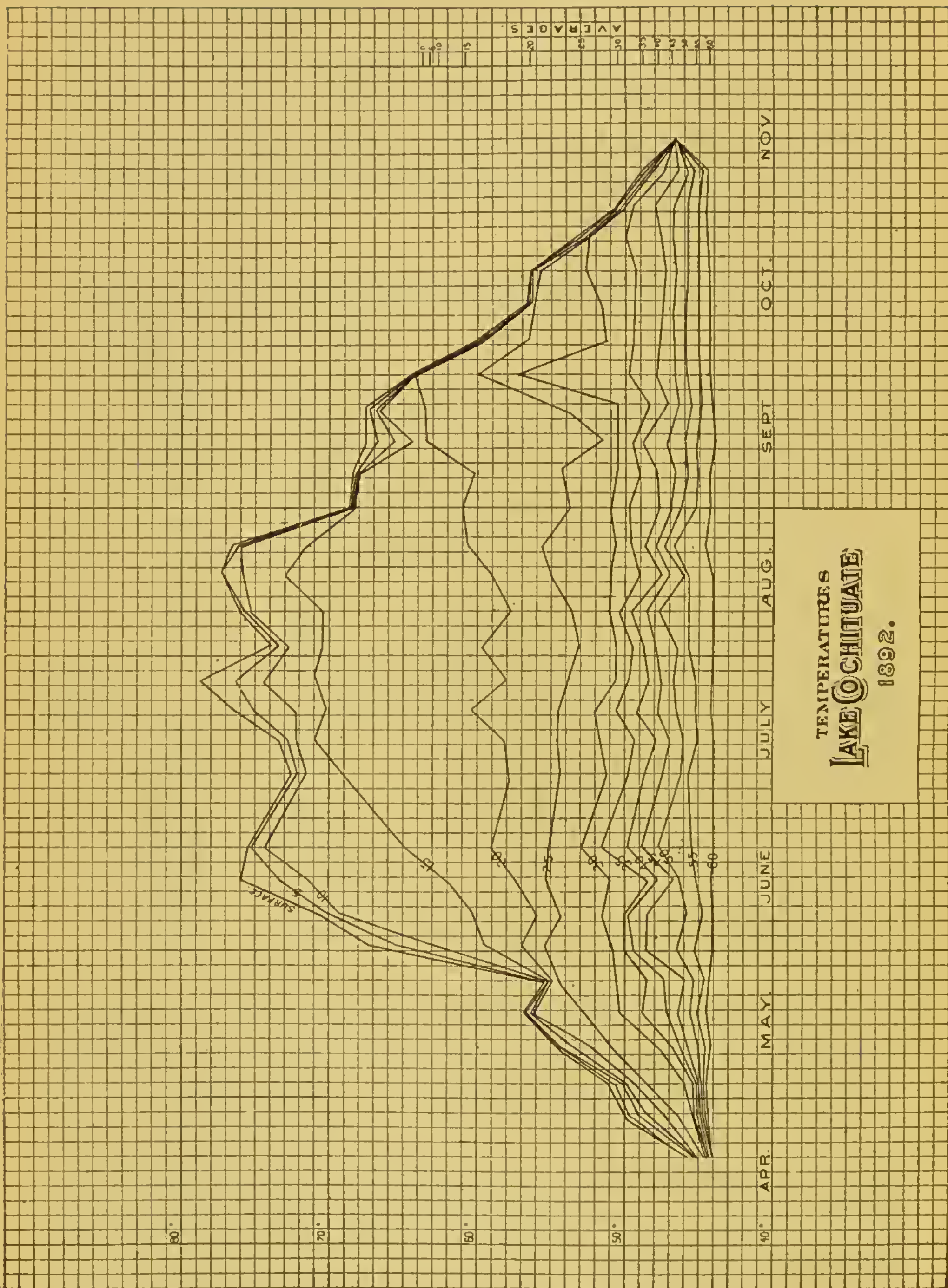
	Temperature, Deg. Fahr	Per Cent of Dissolved Oxygen.
Surface	74.7	85.88
6 ft. below surface	74.7	85.06
12 ft. " "	70.9	58.97
14 ft. " "	——	0
15 ft. " "	——	0
17 ft. " "	——	0
19 ft. " "	——	0
21 ft. " " (bottom)	62.8	0

RESERVOIR NO. 4, BOSTON WATER-WORKS (AUG. 20, 1891).

Surface	74.7	84.50
10 ft. below surface	70.9	84.42
20 ft. " "	61.9	28.02
30 ft. " "	70	27.42
35 ft. " "	54.7	16.28
36½ ft. " " (bottom)	54.7	15.10

"The contrast in the condition of the water in these two reservoirs is very striking. Reservoir No. 3, in which the oxygen is exhausted at a depth of 14 feet, receives a not inconsiderable amount of direct pollution from the towns of Marlborough and Southborough, while the drainage area of Reservoir No. 4, as has been already said, is very sparsely populated."

The following chart, which graphically shows the temperature variations during the summer season for different


TEMPERATURES
LAKE COCHITUATE
1892.
APR.
MAY.
JUNE
JULY
AUG.
SEPT
OCT.
NOV.
AVERAGES
SURFACE
40°
50°
60°
70°
80°

depths of Lake Cochituate, was prepared by Desmond Fitz-Gerald for the report of the Boston Water-works. It will be noted that the temperature curves run together at the times of the semi-annual "turn-over."

As supplementary to his investigation concerning the amount of dissolved oxygen in the water of ponds and reservoirs at different depths during the summer months, Dr. Drown made similar determinations during severe winter weather, when the waters in question were covered with thick coatings of ice. The winter results fully confirmed those of summer, and showed that with exclusion of air the dissolved oxygen diminished in proportion to the quantity of organic material present, "reinforcing the argument for the storing of clean water in clean reservoirs." *

As a result of the "turning over" in the spring and autumn the waters of lakes and deep reservoirs possessing dirty bottoms become fouled to a greater or less degree throughout their entire masses by virtue of the mingling of the waters of all layers during these periods of vertical circulation.

The deeply stained water of the bottom imparts a shade of its color to the body of the water at large, and the nitrogenous matter in solution, quickly oxidizing to "nitrates," furnishes food for countless millions of "diatoms," whose growth, development, and decay cause many of the unpleasant tastes and odors with which our city supplies are so frequently afflicted.

The Boston Water-supply Department has made extended study of the coloring-matter so common to the stagnant layer, and of the observed facts that the color at first

* Mass. Bd. Health, 1892, 331.

An interesting case of trouble from insufficiency of dissolved oxygen in the water of the Schuylkill River has already been referred to.

deepens on exposure to air and afterwards bleaches out. The department finds that these phenomena are more strongly marked in proportion as the bottom-water is rich in salts of iron and manganese.

Those familiar with the properties and behavior of ferrous and ferric salts would have predicted that the soluble and light-colored ferrous compounds would, upon exposure to the atmospheric oxygen, oxidize to darker ferric salts, and ultimately fall as insoluble hydrated oxide, leaving the water bleached.

Sundry vegetable and peaty extracts are exceedingly difficult to decolorize, and waters containing them cannot be rendered colorless by storage in presence of light and air in a period short of many months. Improvement in color always results from storage, but its entire removal is often impossible.

FitzGerald reports the following seasonal changes in color of the waters of the Sudbury: The highest color is attained in the month of June, and then it rapidly lessens until September. Towards the end of October the color increases again until December, and then decreases until it reaches its yearly minimum in the middle of March. He offers the following explanation: In the early spring the swamps are overflowed and the color is low on account of dilution. Concentration causes increase in color until early summer, after which time the swamp pools cease to overflow, and consequently the brooks grow clearer. Autumn rains wash highly stained water into the streams, increasing their color, which is afterwards lessened in winter by the freezing up of the swamp sources.*

Much more recently FitzGerald has experimented regarding the action of lights of different colors on the reduction

* "Metro. Water-supply," Mass. Bd. Health, 1895, Appendix 3.

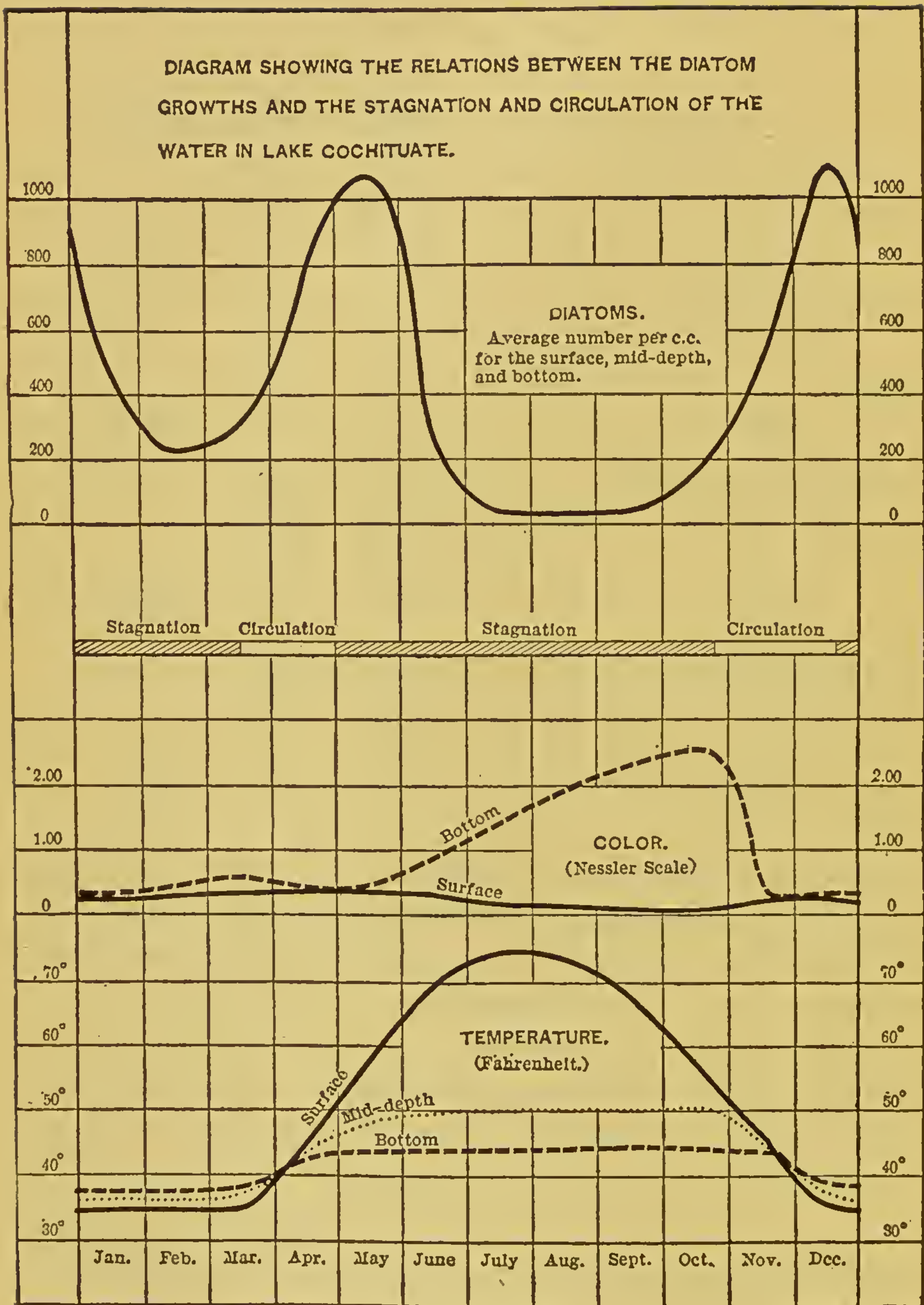
of the brown color of water. The water under experiment was exposed during one month of summer in bottles of colored glass.

	Original Color.	Final Color.	Per Cent Reduction in Color.
In white bottle............	1.05	0.39	
" " "	0.85	0.19	
Mean................	0.95	0.29	69.48
In blue bottle..............	1.02	0.39	
" " "	0.85	0.24	
Mean................	0.93	0.31	66.66
In yellow bottle...........	1.02	0.58	
" " "	0.85	0.46	
Mean................	0.93	0.52	44.09
In red bottle..............	1.02	0.54	
" " "	0.85	0.47	
Mean	0.93	0.50	46.24

To return for a moment to what has been said concerning the growth of diatoms, the following interesting chart, prepared by G. C. Whipple,* makes the relation of such growth to the periods of vertical circulation very distinct:

"The cell-contents of these algæ consist of a membrane, cell-sap, nucleus, chromatophore-plates, and sometimes oil-globules and starch-grains. Biologists are at the present time most interested in the oil-globules, because it is being proved that the oils present in the micro-organisms are the direct cause of many of the bad tastes and odors of certain drinking-waters."

* "Observations on the Growth of Diatoms in Surface-waters."



(AFTER WHIPPLE.)

Among other conclusions Mr. Whipple holds that diatoms flourish best in ponds having muddy bottoms; that their growth is directly connected with the phenomenon of stagnation; that their development does not occur when the lower strata of water are quiescent, but rather during those periods when the water is in circulation from top to bottom; that the two most important conditions for their growth are a sufficient supply of nitrates and a free circulation of air; and that both these conditions are found during the periods of vertical circulation.

In view of what has been said the bottom of a proposed reservoir should, so far as possible, be cleaned of all varieties of vegetable material, and it is even desirable to also remove a portion of the upper soil, as it commonly carries quantities of organic remains. Decomposition of recently killed vegetation takes place under water quite rapidly at first, but the process is shortly converted into one of exceeding slowness, particularly where the covering water is deep. So permanent, in fact, is timber which has been deeply submerged that the oaken piles which in prehistoric times supported the buildings of the Swiss "lake-dwellers" are still firm and solid, although black in color. Alternate flooding and exposure to sun and air is quickly destructive of vegetable matter, and as a result a reservoir with very gently sloping sides furnishes conditions favorable to a contaminated water-supply, particularly if it be liable at times to considerable reduction in depth of water. Even though the level of its contents be always maintained at high-water mark, sloping sides would permit thin layers of water to be overheated by the summer sun, thus encouraging abundant growth of aquatic plants, which subsequently decay, to the damage of the water.

It is especially undesirable to permit the bottom of a

storage-reservoir to remain exposed for more than one season, for the reason that vegetation will develop in such quantity as to greatly damage the water when the bare slopes are again submerged.

Owing to experience already obtained in such matters the Boston authorities propose to remove the soil from the site of the new Nashua reservoir (about seven square miles of area) at a cost of $2,909,000. "In order to determine the amount of soil to be removed a number of test-pits were dug in representative localities to a depth of three feet, and from the sides of these pits samples of the soil were carefully collected at different depths. Analyses demonstrated that the amount of organic matter in the ground was generally so small below the layer of black loam that it would be necessary to remove only this layer." Some 800 holes were dug to determine the average depth of this layer, and it was concluded to remove 9 inches from the wooded portions, and 11½ inches from the cleared lands.*

It would be best, in this connection, to give a short abstract from Dr. Drown's final report. He says:

"In order to determine in any case just how far it is necessary to go in the removal of the surface-soil a knowledge of the composition of the soil, based on chemical analysis, is a much surer guide than the unaided eye. It is not merely a question of the effective cleaning of the bottom and sides of the reservoir, but also of avoiding the expense involved in stripping the soil to a greater depth than is necessary. In connection with the investigations of the State Board of Health relative to a water-supply for the city of Boston and its suburbs surveys have been made for an immense storage-reservoir on the south branch of the Nashua River above Clinton, and it was thought desirable that a

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* Mass. Board of Health, 1895.

thorough knowledge of the character of the soil should be obtained as a basis for determining the amount which it would be necessary to remove to obtain a clean bottom and sides practically free from organic matter. Samples of soils representing sections of the ground to a depth of 3 feet were taken in nine places, and in one case at the bottom of a mill-pond.

"Each of these nine sections was divided into six or seven samples for analysis, the upper portion being divided into thin layers of 2 to 3 inches, the lower portions, with less organic matter, into layers of 6 to 12 inches in depth.

"The amount of organic matter in these samples was determined, after careful drying to a constant weight at 100° C. (212° F.), by heating the samples to a bright red heat. The loss on ignition thus obtained represents approximately the organic matter in the samples. But in order to get a better knowledge of the character of this organic matter the amounts of carbon and of nitrogen were also determined in each sample—the former by combustion in oxygen, the latter by the Kjeldahl method.

"The largest amount of organic matter found was from a swamp at the head of the Boylston mill-pond, and the next largest from the hillside near the site of the proposed dam. In all the series there is usually a rapid falling off in the amount of the organic matter below a depth of 9 to 11 inches. At the depth of 3 feet the amount of organic matter, as shown by the loss on ignition, in no case reaches 2 per cent, and in the majority of the cases it is below 10 per cent. The mud taken from the bottom of the mill-pond at different points contained very variable amounts of organic matter, from almost nothing at one place in the shallow portion to nearly 15 per cent in the deeper portion.

"As a preliminary conclusion, based on the facts determined in this investigation, it may be said that the effect of

the organic matter in these various soils on the water in contact with them is simply a question of its amount, and that its origin and composition seem to be without marked influence. The watershed from which the samples were taken is very sparsely populated, and the organic matter in all cases is mainly of vegetable origin.

"It is probable, therefore, that we need only concern ourselves with the amount of organic matter in a soil of this character in determining the necessity of its removal, and as a provisional standard we may perhaps fix 1½ to 2 per cent of organic matter, as determined by the loss on ignition of the sample dried at 100° C. (212° F.), as the permissible limit of organic matter that may be allowed to remain on the bottom and sides of a reservoir." *

As an instance showing the necessity of thorough removal of the upper soil-layer from a proposed reservoir site if bad odors are to be avoided the very recent experience with Reservoir M of the New York Croton water system is a case in point. The following is taken from the New York *Times:*

"The residents of Purdy's Station, N. Y., lying at the foot of Reservoir M, have been very considerably agitated lately over the malodorous atmosphere which prevails about the reservoir and pervades the inmost recesses of Purdy's dwelling-houses.

"So obtrusively penetrant has the odor become within the last few weeks that many folk, believing the water to be infected, have closed up the wells from which they procure their drinking-water, and some have even been forced to abandon the hamlet as a residence until the atmosphere regains its purity and pleasant odor.

* No stripping of the soil from the bottom of the Vyrnwy reservoir, supplying Liverpool, was done, but the water is filtered before delivery for consumption. Filtration is so common in Europe that the same care in storage is not so necessary as it is in this country, where the practice is to pipe the raw water direct to the consumer.

"On July 29, 1895, the upper gate of the reservoir was pulled up and the great flood of water which had been in process of collecting for a year began to gush down the Titicus, over Isaac Purdy's old sawmill-dam, on to the east branch of the Croton, and into New York City, at the rate of 40,000,000 gallons per day. It was then that Purdy-ites began to detect in the atmosphere a smell which seemed to be a combination of everything offensive.

"An investigation was begun, and it was soon proved to everybody's satisfaction that the decayed grass in the bottom of the reservoir was exclusively responsible for the odor.

"It was about five years ago that the work on Reservoir M was begun, and its completion dates from one year ago. It was built on condemned land on which formerly were gardens, orchards, and dwelling-houses, through which meandered a small stream known as the Titicus. The 1000 acres of land covered by the reservoir were cleared of everything excepting the growth of grass, which was left in most cases intact, or at least was not ploughed."

Other reservoirs of the same system gave similar trouble for a number of years after their construction.

Depth of reservoirs is not so important as the presence of food-supply in the matter of the existence or absence of organisms. The Massachusetts Board of Health reports the case of Pilling's Pond, a very old storage-reservoir, eighty-five acres in surface, with an average depth of only three feet. No abnormal growths appeared in this reservoir, nor did the water become offensive, although its temperature at times reached 80° F. The explanation offered is that, owing to the age of the reservoir, the bottom mud no longer contains food-supply.*

Sulphuretted hydrogen frequently adds its disagreeable

* Mass. Board of Health, 1890 [1], 749.

smell to the offensive odors occurring in new reservoirs, particularly shallow ones. The decomposition of vegetable material, killed by flooding, causes a reduction of the sulphates present to sulphides, and these sulphides are further acted upon by the acids also formed by such decomposition, with liberation of the foul-smelling gas. The author found this gas on one occasion due to a somewhat unusual cause. The reservoir-dam had been built of blast-furnace cinder, and the water was, in consequence, strongly impregnated from the sulphur compounds contained therein.

Waters from underground sources should be distributed for use as soon as possible after they have been brought to the surface; for, as we have seen, they are commonly well supplied with plant-food in solution, and, under the influence of light and air, there is danger of abundant development of objectionable algæ if much time for open storage be allowed.

With surface-waters the case is quite the reverse, and long storage becomes a distinct advantage if the reservoir be clean.

Sedimentation of suspended impurities, and destruction of bacteria by simple lapse of time, are two sources of benefit arising from impounding of surface-water.

Bacteria often die but slowly, and although a large percentage of their number will disappear through storage, it should not be forgotten that they are very small and very light, and consequently are very long in settling; so that it should not be expected that a reservoir could do the efficient work accomplished by a filter.

The Boston Water Department publishes the following table, showing the influence of sedimentation as measured by the number of bacteria per cubic centimetre of water:

Month.	Chestnut Hill Reservoir Gate-houses.			Chestnut Hill Reservoir.			Brookline Gate-house.	Taps.	
	Sudbury.	Cochituate.	Effluent.	Surface.	Middle.	Bottom.		Park Square.	Mattapan.
January, 1894....	294	20	97	81	168	236	52	73	54
February "	436	141	148	....	....	....	70	42	84
March "	137	74	110	48	101	110	40	32	30
April "	48	22	76	25	77	50	57	32	72
May "	54	58	71	152	260	298	47	30	107
June "	65	248	90	36	180	187	80	157	92
July "	789	1553	1080	169	647	650	164	46	80
August "	26	192	221	100	569	701	83	102	65
September "	65	192	219	69	152	432	64	109	60
October "	95	387	242	38	181	225	126	29	42
November "	85	161	228	48	120	299	37	50	30
December "	49	44	124	....	....	....	17	27	22
Mean........	179	258	226	77	246	319	70	61	62

Percy Frankland found the following numbers of bacteria per cubic centimetre in Thames water at the intake of the Grand Junction Company, and in water from the large reservoir of the company, where the greater part of it had been stored for six months, and none for less than one month:

Intake............................ 1991 bacteria
Reservoir......................... 368 "

The value of sedimentation was shown at Philadelphia during the prevalence of typhoid fever in that city in 1891. "By much the highest mortality is in the twenty-ninth and thirty-second wards. This is an elevated section of the city, newly improved and occupied for the most part by well-to-do people. The drainage is good and the laws of health are doubtless as well observed as in any other portion of the city. But these wards are too high to draw water from the subsiding reservoir, and they are accordingly furnished by direct pumpage from the river. This is the case also in the twenty-eighth ward adjoining, and the district

so supplied extends southward including the fifteenth ward, another well-to-do part of the city where typhoid is especially prevalent. These four wards, furnished by direct pumpage, have a population of 184,000, and report 317 cases of typhoid fever, or at the rate of 172 to 100,000 inhabitants.''

The West Middlesex Company causes its water to pass through two storage-reservoirs before it is delivered upon the filter-beds. The influence of such passage is seen in the following counts of bacteria as made by Frankland:

Intake at Hampton	1437	per cubic centimetre
After passing first reservoir	318	" " "
" " second "	177	" " "

The influence of precipitating mud in hastening the fall of bacteria was investigated by Krüger.* By the use of one half gramme of fine sterilized potter's clay per litre of water he obtained the following counts of bacteria per cubic centimetre of water. The temperature was maintained at 55° F.

	Water with Clay.			Control Water Containing No Clay.		
	Top.	Middle.	Bottom.	Top.	Middle	Bottom.
After standing 2 hours	575	887	33,495	5340	6110	5480
" " 20 "	521	155	43,595	5960	6710	6210
" " 50 "	6933	6190	66,350	7230	5987	6924

As has been pointed out elsewhere this action was to have been expected, in view of the well-known tendency of falling solids to drag down other matters with them even, at times, when such other bodies are in solution. Bac-

* *Zeit. f. Hygiene*, VII. 86.

teria, being in suspension, are more readily influenced by the depositing silt. The very large counts observed in the bottom samples of the water containing clay are doubtless due to the fact that the sterilized clay contained, abundant food for the germs and favored their rapid multiplication during the period of observation.

The most apparent advantage to be obtained from storage is doubtless the removal, by sedimentation, of those suspended materials, mostly of mineral character, which cause unsightly turbidity in water.

The theory of the clearing of water by settlement, and the most economic size for purely sedimentation-reservoirs, are questions which have been exhaustively discussed in our engineering societies by such men as J. A. Seddon, Whitney, and others, and reference must be had to their interesting and voluminous papers for full information.

One or two very condensed abstracts would be in keeping here. Speaking before the Engineers' Club of St. Louis, Seddon says:

"There is much need of some definite knowledge of how water clears, or what are the laws under which the sediment in suspension in it passes out.

"As far as the water-works engineer is concerned, the problem of simple settlement is confined to the consideration of a mixture of small particles of greater specific gravity than water, and of different sizes, which are at the commencement of settlement about uniformly distributed through the water, and which gradually settle out of it. That there must be some law or laws by which they settle out would hardly be questioned; yet, while any number of theories have been presented, I do not know of an effort that has been made public to substantiate or value any of them by a careful system of experiment and observation.

"With the theories that have been advanced it is an open

question whether settling-basins should be shallow or deep, open or covered, what is the economic number in a given system, and even whether the settlement should be accomplished by a system of filling and drawing in rotation, or by a system of constant flow through the basins, water-works under each system being at present in process of construction, with the chances of making standing blunders on a large scale.

"Experiments and observations were undertaken as a preliminary to the design of the settling-basins for the St. Louis Water-works extension.

"For the wind to have no effect we would conclude that the simple wave motion existing over the greater part of a basin was in itself no hindrance to settlement, and that the revolution of the basin, produced by the tangential force of the wind on its surface, was insignificant compared with the effect of the internal motion. It is hardly thought that this question of the wind effect is settled by the data, but it certainly shows much less than might be expected, and was a great surprise to me.

"But, leaving theory out of the question, the data alone were enough for the economic design of the settling-basins; for they show as a fact in all cases that there is not much difference between the clearness from top to bottom of the basin, and for settlement beyond twenty-four hours so little that the problem in St. Louis was practically one of economic storage of volume, and that an expensive covering to protect the basins from wind was not justified. As the economy of settlement by filling and drawing, contrasted with continuous flow, had been demonstrated by a former system of experiments, the above furnished all the information needed."

A statement of the experiments proving the economy of settlement in quiet basins over settlement during con-

tinuous flow will be found in *Engineering News*, vol. XXII., page 607, December 28, 1889, *et seq.*

Among the comments upon Seddon's paper was the following:

"The experiments just referred to upon settling-basins into which a continuous current is allowed to flow, and upon others permitted to stand without filling or drawing for a period of settlement, have shown for Mississippi water that it is more economical of storage capacity to use the latter method. To secure the same result in the same time by the two methods it is necessary to reduce the motions in the water to the same amount, approximately. The size of basins necessary to produce the effect when the flow is constant is greater than that necessary when the basins are filled, allowed to stand undisturbed for a time, and then drawn off. In the Mississippi water there is a large proportion of very fine sediment which requires a long time to effect a settlement, and there is some which will not settle out except under the quietest possible condition."

Whitney calls attention to the fact that "as the material in suspension grows finer the weight of each particle decreases so much more rapidly in proportion than its surface there is, relatively, a larger amount of surface area in these fine particles, and a great deal of surface friction in their movement through a medium. Consequently they settle very slowly."

"Ordinary convection currents, induced by normal changes of temperature, would be sufficient to keep these fine particles in suspension, as it is known that currents of air keep fine particles of dust and ashes in suspension." *

Although great storage-reservoirs must of necessity be open, those used for service should unquestionably be cov-

* Wiley's "Agric. Anal." I. 180.

ered, especially so if the water to be stored be from an underground source. We have already seen that exposure of subterranean waters to sunlight commonly results in development of objectionable vegetable growths. The writer recently visited the somewhat peculiar reservoirs at Paris which hold the Vanne spring-water, supplying a large portion of the drinking-water used in the French capital. The springs are about 107 miles distant, and the grade of the conduit-pipes is 1 centimetre per 100 metres (0.4 inch per 328 feet). In order to secure sufficient storage, and yet to economize space within the walls of Paris, two reservoirs were built, one on top of the other.* The lower one is constructed of concrete, and 1800 concrete columns support the upper story, which is of brick. This upper chamber is covered by a roof which rests on brick continuations of the concrete columns. The water area in each reservoir is 272×136 metres (892×446 feet), and its depth in the upper one is $8\frac{1}{4}$ feet and in the lower one $13\frac{3}{4}$ feet. The total storage capacity is 200,000 cubic metres (52,800,000 U. S. gallons). The temperature of the water is constantly 48.2° F. in winter and 51.8° F. in summer. No trouble has ever been experienced with algæ growths or odors. Cleaning takes place but once in five years, at which time about half an inch of compact hard deposit is removed. The reservoirs hold a supply sufficient for about six days.

"The gravitation supply for the city of Naples, brought in from Urcicoli, a distance of 31 miles, at a cost of about L1,400,000 ($280,000), is distributed from service-reservoirs located in the hills overlooking the city. They lie within the bosom of Capedimonte Hill. The water is collected from springs, scarcely sees light on its passage to Naples through the aqueduct, and is there received into the

* The Montmartre reservoirs of Paris consist of three superimposed chambers instead of two.

service-reservoirs at Capedimonte for the lower level districts, and in the valley of the Fontanelle for the higher level districts. The water is distributed at an almost constant temperature of 55° F. The reservoirs instead of being placed on the hills are within them at a depth of some 150 feet from the surface. This situation, so admirable in itself, but which would usually be so costly, was probably forced on the engineer by the fact that the hill had already been honeycombed for building-stone; some of the old mines or "Caflisch" were enlarged and made use of for the reservoirs and the outlet-mains to the city. A visit to these reservoirs will not be easily forgotten, and the contrast between the bright hot summer's day left overhead and the funeral darkness and icy chill of the lower region is extremely startling to a visitor. The low service-reservoir consists of five galleries excavated parallel to each other. Their dimensions are 35.4 feet in height, and 30.3 feet greatest width. The depth of water is 26 feet, and the galleries are separated by a space of about 30.3 feet of rock left unexcavated. The 1st, 2d, 4th, and 5th galleries communicate, so that the five galleries make three completely isolated basins. The lengths of Nos. 1, 2, and 3 are 830 feet, and of the remaining two 666 feet. The variation in length was necessitated by the presence of a disused mine near No. 4 basin. The capacity of the five basins is 17,600,000 imperial gallons.* The veins in the rock filled with scarpine were well cleaned out and replaced with solid masonry as required. Up to five inches above top-water line the sides of the excavation were plastered in cement of varying thickness, from two inches at the base to one half an inch at the top. The plaster was put on in two layers."

Referring to the covering of the London reservoirs, the

* 21,120,000 U. S. gallons.

1 imperial gallon = 1.2 U. S. gallons.

official examiner, Sir Francis Bolton, in his "London Water-supply," says:

"No greater improvement in water-works construction was ever effected than that of covering the reservoirs, and thus protecting the water from all atmospheric impurities as well as from light and heat. In proof of its efficiency it may be mentioned that reservoirs which when open required cleansing out twice a year, owing to the vegetable growth, aerial impurities, and animal life constantly accumulating therein, have been found to be perfectly free from any objectionable deposit for five years after being covered over."

The lining of a service-reservoir is an important matter, and, unless properly looked after, may result in serious difficulties.

Phipson reports a case* where a new subterranean reservoir, built to store rain-water, and lined with hydraulic cement of bad quality, permitted its contents to become so charged with calcium hydrate as to be strongly alkaline to litmus paper. The water was thus rendered useless for domestic purposes.

Where possible of application, very excellent results are obtained from the use of a lining of asphaltum. The following is taken from a report of the work done on the new reservoirs of Portland, Ore.:

"Among the most interesting features of the construction of Portland's new water-supply system is the use of asphaltum for the finishing coat of the reservoir-linings.

"Since the earliest history of man asphaltum has been extensively used in structural work in a variety of forms. The builders of the ditches and reservoirs that supplied ancient Babylon employed it to save leakage; the wonderful

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* *Chemical News*, LXX. 3.

works of the Syrian and Egyptian builders all attest the use of this valuable material.

"The ancient artisans used the soft, pure asphaltum from the fountains of Is and from the shores of the Red Sea. Their works, uncovered by moderrn searchers, show the material in as good condition as ever. The disinterred works of the California Indians bear the same testimony. It has not changed by time.

"The Syrians, the Egyptians, and the Indians took it and applied it as they found it; therefore it lasts eternally, as it would in its native beds. In itself it is indestructible except by fire. It is only the spurious article, adulterated and weakened, that fails.

"The lesson taught by the testimony of centuries has been applied in the Portland work. The asphalt used in the reservoirs is pure natural bitumen, and it seals every pore of the brick and concrete backing as wax seals a jar of fruit or a bottle of wine. There can be no leaks so long as the linings stand."

A very uncommon necessity arose, some two years ago, of disinfecting the reservoir-lining at Buffalo, N. Y. A typhoid fever epidemic of some magnitude was prevailing in the city at the time, caused by the entrance of the very foul water of a sewage canal into the public supply. As polluted water had unquestionably been pumped into the distributing-reservoir, it was determined to empty and disinfect the same before continuing its use. A very sharp discussion ensued among the local authorities as to the relative merits of chlorine and bromine for such disinfection, the latter having been already purchased for the purpose by the Board of Health.

As between the two agents proposed the author decided in favor of bromine, as follows:

"Beyond question chlorine is, in general, a more ener-

getic agent than bromine, and manifests a greater intensity of chemical activity, tending to the breaking up of molecular structure, but as to germicidal power they are practically the same. Either of them is certain death to living organisms.

"For use as a disinfecting solution the liquid form of bromine, under the ordinary conditions of temperature and pressure, its greater solubility in water, and the comparative permanence of the solution so formed, render it more suitable and convenient than chlorine, and any small difference in actual cost per pound should not be admitted as a factor in the consideration.

"Chlorine* is to-day sold as a liquid under pressure (60 pounds per square inch), but its boiling-point, at ordinary pressure, being about 30 degrees below zero, and the amount of the gas capable of being held in solution in water being about 2 per cent, the waste of gas during the manufacture of 'chlorine-water' may readily be very excessive.

"Bromine is a liquid at ordinary temperature and is soluble in water to about 3 per cent. In preparation of 'bromine-water' any excess of bromine, owing to its high gravity, sinks to the bottom and maintains a constant state of saturation.

"After years of experience in the preparation and use of solutions of the two elements I can state that 'bromine-water' is capable of being prepared more easily and of being preserved for a much longer period than the corresponding chlorine solution.

"Not only is 'chlorine-water' more troublesome to prepare, but it deteriorates quite rapidly when exposed to the

* Liquefied chlorine comes in iron cylinders containing about 90 pounds, at 35 cents per pound, cylinder $16 extra. The latter, when empty, is returnable at full price charged, if in good condition. Liquefied chlorine is made by the manufacturers of coal-tar dyes in Germany, and is used in connection with the manufacture of such dyes.

influence of light and air; and for service such as is desired in Buffalo the question might readily be raised as to whether or not the successive portions of the liquid used were of equal or even of efficient strength at the times of their employment. It would be the simplest of problems to maintain the 'bromine-water' at full saturation strength throughout the entire process of disinfection."

Bromine-water was used in the above instance and was applied as a spray by the help of a fire-engine. The results were satisfactory.

As growing out of a consideration of reservoir-water, it is interesting to note the influence of the channels of distribution, i.e., conduits and city mains, upon the character of the supply. The differences between the following sets of samples, taken by the author at a city intake and drawn from taps at the other end of the town, show the changes in the water resulting from passing through the pumping system and street mains:

	Bacteria per Cubic Centimetre.	
	Intake.	Tap.
January 12	4,022	1502
February 5	3,322	436
April 10	17,665	2425
October 30	1,487	1090

It is instructive, and suggestive of the beneficial action of mains, to note that, for the year ending September 30, 1892, when the lake-water was pumped directly into the Chicago mains from the old short-tunnel intakes, the percentages, by wards, of deaths from typhoid to total deaths were:

Wards less than two miles from the lake	6.0 per cent
" more " " " " " "	5.7 " "

At the time of testing the new filter for the city of Lawrence, Mass., the efficiency was found to be a removal of

98.3 per cent of all bacteria; but by the time the water reached the city hall 99.1 per cent had disappeared. Thus credit should be given the street mains for the destruction of 0.8 per cent of the total germs.

Similar evidence is presented by chemical analysis of water from the same town: *

	Albuminoid Ammonia.	Nitrogen as Nitrates.
Water as pumped to reservoir	.174	.135
Water from reservoir	.144	.146
Water from city tap two miles from reservoir,	.117	.192

Currier gives the following counts of bacteria, showing influence of a flow of twenty-two miles in the Croton aqueduct:

Dobbs Ferry	453 per cubic centimetre
Central Park	175 " " "

Entirely similar results were obtained with the Mohawk River water by Prof. Stoller, and the beneficial action of the Schenectady mains is graphically shown by him in the Thirteenth Report of the N. Y. State Board of Health.

In examining the Freiburg supply Tils found that the water from the reservoir contained fewer bacteria than that from the mountain source. But he also found that the bacteria increased in numbers after passing through the service-mains. Percy Frankland also found that the deep well-water furnished by the Kent Company contained fewer bacteria as it issued from the wells than when delivered by the city mains to the consumers. This is at variance with our experience in this country, and possibly the explanation is that the deep well-waters supplied a large amount of mineral food and thus encouraged bacterial growth.

* Mass. Board of Health, 1890.

CHAPTER VIII.

GROUND-WATER.

THE circulation of water in the soil is governed by gravity and surface-tension, and the latter is in turn affected by the structure of the soil, its composition, and the per cent by volume of the empty spaces between its particles.

The "voids" in the subsoils of South Carolina and Maryland, as determined by Whitney, show as a mean for twenty-three localities 48.73 per cent by volume, the extremes being 37.29 and 65.12.

The rate at which water will flow through a soil * is dependent not only upon the aggregate volume of the voids, but also, and more particularly, upon their separate dimensions; for it can be readily seen that the inhibiting influence of friction will rapidly increase with the fineness of the soil-grain.

This is seen in the following table, extracted from "Physical Properties of Soils." † The rates of flow through a certain depth are calculated for a uniform water-content of 12 per cent.

Soil (Maryland).	Number of Grains per Gramme of Subsoil.	Voids, per Cent.	Relative Time, Minutes.
Pine-barrens	1,692,088,503	40	8
Truck	3,342,323,489	45	16
Tobacco	8,258,269,975	50	33
Wheat	10,357,871,515	55	45
River terrace	11,684,097,513	55	49
Triassic	14,735,778,341	55	56
Helderberg	19,638,258,585	65	100

* In this connection see Wiley's "Agric. Anal." I. 159.

† Bulletin 4, U. S. Depart. of Agric.

Storer gives the following values for the water-holding powers of various soils. The figures show the percentage of water absorbed in terms of the weight of the dry soil, and were determined by drying, weighing, soaking, draining, and again weighing each sample.

Quartz-sand, rounded edges.........	26 per cent
Quartz-sand with flakes of mica......	32 " "
Gypsum (earthy)......................	27 " "
Loamy clay...........................	50 " "
White clay...........................	74 " "
Yellow clay..........................	68 " "
Loam.................................	52 " "
Fertile marly loam...................	59 " "
Limestone-sand.......................	29 " "
Humus................................	180 " "
Peat.................................	201 " "

A word of caution seems proper here. It must be remembered that the above figures show what the sands and soils will *hold*, not what they would *deliver*. No pump could extract that final portion of the contained water which would remain as "moisture," and its quantity would be a very respectable percentage indeed of the amounts given.

"When a soil is only slightly moist, the water clings to its grains in the form of a thin film. When these soil-particles are brought together, the films of water surrounding them unite, one surface being in contact with the soil-particles and the other exposed to the air. If more water enter the soil, the film thickens, until finally, when the point of saturation is reached, all the space between the soil-particles becomes filled with water, and surface-tension within the soil is thus reduced to zero. Gravity then alone acts on the water and with a maximum force.

"In a cubic foot of ordinary soil the total surface of the soil-particles will be at least 50,000 square feet. It follows

that when the soil is only slightly moist the exposed water-surface of the films surrounding the soil-particles approximates that of the particles themselves. If such a mass of slightly moist soil be brought in contact with a like mass saturated with water, the films of water at the point of contact will begin to thicken in the nearly dry soil at the expense of the water-content of the saturated mass. The water will thus be moved in any direction.

"During evaporation the surface-tension near the surface of the soil is increased, and the water is thus drawn from below. In like manner, when rain falls on a somewhat dry soil, the surface-tension is diminished, and the greater surface-tension below pulls the moisture down, even when gravitation would not be sufficient for that purpose." *

Wherever found, and under whatever circumstances, the water of the ground owes its origin to the rain or melting snow.† Attention is called to this point because of a wide-

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* Bulletin 4, U. S. Weather Bureau. Also Wiley's "Agric. Anal." I. 155.

† "Iowa contains a little over 35,000,000 acres of land- and water-surface. Upon this area the mean annual precipitation is about thirty-five inches (including rain and melted snow). Each acre receives 3955 tons of water each year, and the whole State receives the enormous aggregate of 138,000,000,000 tons per year. How is this vast amount of water disposed of? A considerable share sinks into the ground and is stored and held in the interstices of the soil and subsoil, and made available for plant-growth. The amount that is thus absorbed and held depends upon the depth of soil above the more impervious strata, and its porosity and capacity to receive moisture. In this prairie region the amount that enters the soil and is held there temporarily is much larger than in hilly or mountainous countries. The annual surface flow or run-off in the streams amounts, on an average, to about 30 to 40 per cent of the total rainfall. This leaves 60 to 70 per cent to be disposed of by percolation into the soil, evaporation by sun and air, and by transpiration through plants. In the growth of cereal crops a very large percentage of the soil-moisture is consumed, but the ratio it bears to the total has never been satisfactorily determined. It has been ascertained, however, by careful experiments, that in the production of a ton of the dry matter of corn over 300 tons of water are required. In the growth of a ton of oats more than 500 tons of water are consumed. These figures illustrate the fact that by making the soil more porous and by the production of vast crops we have lessened the flowage in the streams and greatly reduced the area of our ponds and shallow lakes. The re-

spread notion that the wells of fresh water often existing in the immediate vicinity of the ocean are fed with sea-water from which the salt has been removed by percolation through the sand of the beach. Much to the writer's surprise, this inference is permitted in an engineering work of national fame. In some cases the fresh water found in the sand of the seashore originates some considerable distance inland, and the wells intercept it on its way towards an outlet in the sea; in other instances its origin is due entirely to very local rains, and its storage in the loose sand is owing to its being specifically lighter than the surrounding sea-water.

An instance of this kind is met with in the island of Muskeget, near Nantucket. The island is practically a mound of sand, raised but a few feet above the level of the ocean,

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cent drought has worked to the same end." (Iowa Weather Service, December, 1895.)

The following curious instance of reinforcement of ground-water is given in Fernow's "Forest Influences":

"The influence of forests on fogs and clouds has been frequently mentioned and observed in single cases. The fog seems to linger in the woods after it has cleared off elsewhere. Trees also act as condensers, as gatherers of dew, hoar frost, and ice, and the latter phenomenon is especially remarkable in the so-called ice-storms, where the accumulation is so great as to overload and break the larger limbs and branches. In these cases, however, the trees act like inorganic bodies. This is illustrated by a celebrated case on the island of Ascension, the details of which are due to Prof. Cleveland Abbe, who in 1890 personally inspected the phenomenon. This case is especially worth quoting, because its records have been so badly understood. The principal water-supply for the garrison of this naval station is gathered several miles away, at the summit of Green Mountain, the upper part of which has always been green with verdure since the island was discovered; almost all of this water comes from slight showers and steady dripping of trees enveloped in cloud-fog on the windward side of the mountain. Every exposed object contributes its drip; these do not condense the water, they simply collect it mechanically after it has been condensed in the uprising cooling air. Whatever fog-drops are not thus collected sweep on over the mountain and quickly evaporate again. Thirty years ago or more efforts were made to plant a few trees in the arid spot at the garrison landing; none survived, but some few new shrubs were added to the flora of the mountain-top; extensive additions were also made to the mountain reservoirs and drip-collectors and pipes of the aqueduct system. The few artificial scrubby plants have had no influence whatever in increasing the water-supply.

and it is perhaps a mile in width. It was formed and is maintained by ocean currents, and is covered by a scanty growth of grass. Anywhere upon this island fresh water may be obtained by digging down two or three feet in the sand. Necessarily the water to be secured from such a source is limited in quantity. Under the general head of deep-seated water we shall see that fresh water may reach the ocean from very distant sources, and under a head so great as to cause a veritable " boiling spring " miles out at sea.

A very commonly received conception of the occurrence of ground-water is that it moves in very definitely localized streams, and that, to be successful, a well must be sunk directly into one of these. Of course the conformation of the country may, at times, cause this popular notion to closely coincide with the truth, but a more general description of the occurrence of ground-water would be that of a widely extended sheet, and the expression " water-table " has been adopted with that view in mind.

Underground streams, some of large size, do certainly exist, especially in limestone districts,* but their character would hardly permit of their being classed as typical " ground-water." If considered at all, they should be properly placed under " deep-seated water," but their importance as means of supply is entirely insignificant.

The mean height of this " water-table " (i.e., its distance from the surface of the ground) is governed by the average

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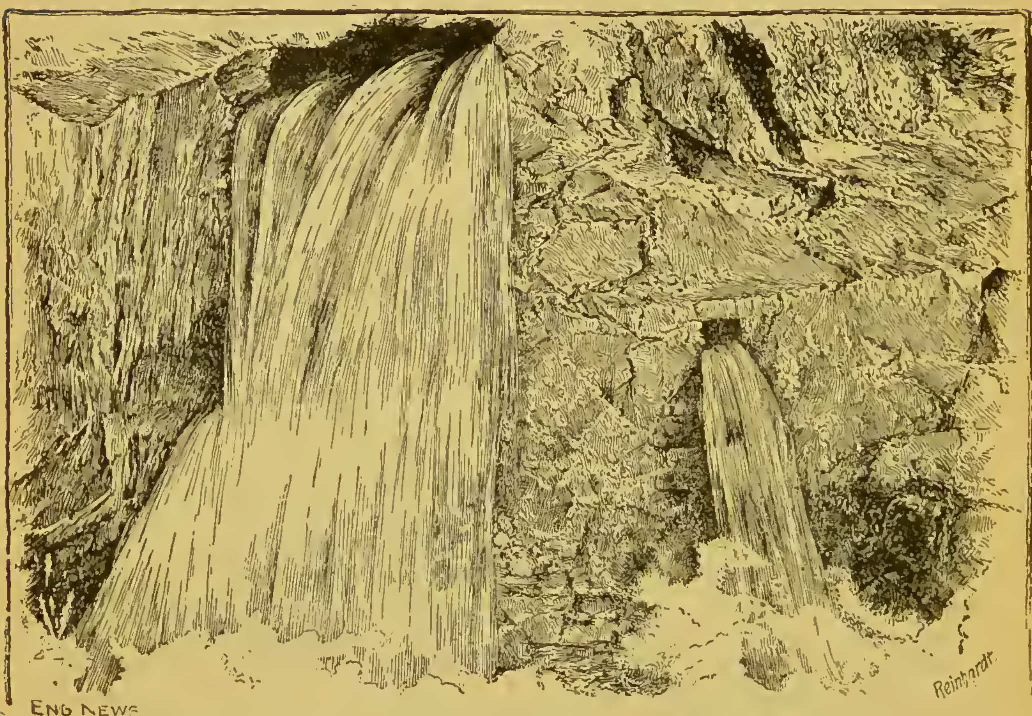
* "The most remarkable well I have ever seen was on the old battlefield of Stone River, in Tennessee. A man in digging for water struck an underground stream He made the hole big enough to hold a water-wheel. The stream ran the wheel and pumped water up to the owner's house. Underground streams, of course, are common enough. They are frequent in the limestone region of Texas, in the gypsum region of New Mexico, in the Appalachian region, and in the limestone region of Iowa and Missouri. The very fact that these streams are flowing shows that they are seeking a base level, and hence it is useless to try to tap them by artesian wells, because the water will not rise." (R. T. Hill.)

rainfall and the opportunities for local drainage. The delivery being into the rivers and streams of the district, or into the sea, there is always a slight inclination of the water-surface towards those natural drains, more especially in their immediate vicinity. The seaward slope of the water-table of the south half of Long Island, for instance, is from 8 to 12 feet per mile.



UNDERGROUND STREAM ENCOUNTERED IN DRIVING TUNNEL FOR WATER SUPPLY INTAKE, MILWAUKEE, WIS.

When a well is sunk into this layer of ground-water, and draught by pumping made thereupon, a "cone of influence" is established, whose apex is at the bottom of the well, and whose lateral elements coincide with a new and steeper slope of the surface of the water-table. The steepness of this slope, and consequently the area of the base of the "cone," will in large part depend upon the character of the soil through which the water is caused to flow. If the grain

of the soil be fine, the high degree of friction will greatly impede the velocity of the water, and as a result the slope will be steep and the base of the cone contracted, while the reverse conditions would obtain in a soil of open, sandy texture.

Throughout the semi-arid region of the great Western plains the ground-water and deep-seated water development has received a very large share of attention indeed; for if it were true that the "underflow," which unquestionably exists there, constantly received inexhaustible reinforcements from the mountains farther west, it would be very apparent that sterile wastes might quickly be transformed into fertile meadows by the sinking of wells and irrigation on an extensive scale.

It is erroneously held by many otherwise well-informed people that the ground-water supplying the wells of large portions of the great plains of Colorado, Kansas, Nebraska, Wyoming, and Texas is derived from the melting of the snow on the Rocky Mountains; but, as is shown in the reports of Professors Hay and Hill,* "the great body of the area of the plains is cut off from contact with the mountains by deep river-trenches, which make it impossible for them to receive any benefit from the melting of the mountain snows." This is shown graphically on the next page.

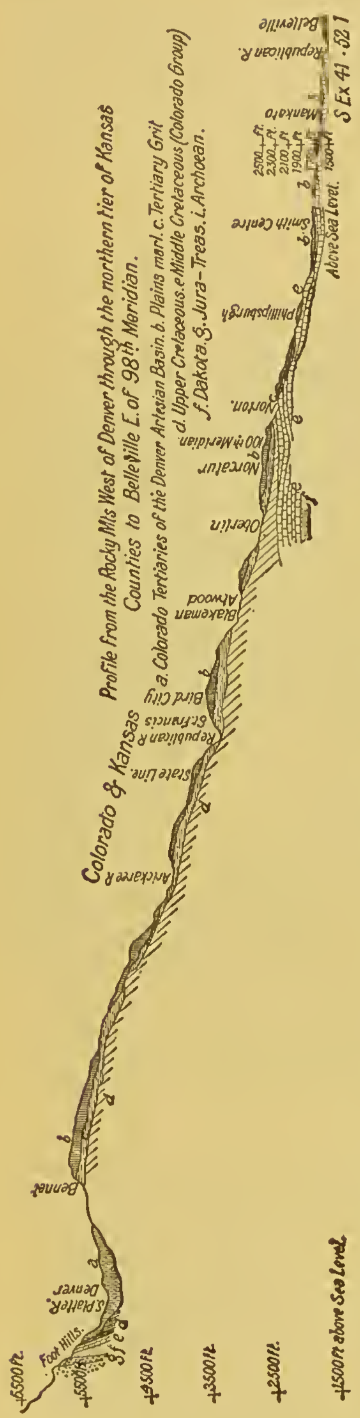
Referring to the "underflow" of the semi-arid region, Follett says:

"The question of utilizing this underflow for general irrigation has been studied in a desultory way for several years. Unfortunately the investigators have all been either real-estate boomers or enthusiasts, and have generally reached conclusions first and then looked for facts to substantiate them.

"Two years ago last fall I was employed as assistant

* Senate Doc. 41, part 3, 52d Congress.

engineer for the artesian and underflow investigation of the U. S. Department of Agriculture, of which Col. E. S. Nettleton was chief engineer. Under instructions from Colonel Nettleton I was detailed to collect facts bearing on this problem on the possibilities of general irrigation from the underground waters. Many facts were gathered, all tending to confirmation of the assumption that the sheet-water, broadly speaking, receives none of its supply directly from the mountains. This is important, as tending to assist in computing the possible supply. Its source must be the western portion of the great plains, with very little, if any, foot-hill drainage. Here the rainfall is light, and the soil in general not such as will freely imbibe water, and the evaporation is rapid. All these conditions tend to show that the supply of underground water must be limited.



" The next step will be to determine, if possible, the rate of movement of water in sand. Some English engineers determined by experiment that water moved through sand at the rate of one mile per year, or $\frac{1}{5}$ inch per minute. Mr. Donald W. Campbell reports that he made some rough experiments in the Gila River sand,

in Arizona, and thought he detected a movement of $\frac{1}{4}$ inch per minute. I tried in Cherry Creek sand, very coarse, and in a channel having about 25 feet per mile of fall. I could detect no movement, but my method of work was crude."

He concludes that:

"(1) The underflow is not supplied from the snow or rainfall of the mountains.

"(2) Its rate of movement in the sand is very slow, hence:

"(3) The amount which may be drawn from it without permanently lowering its level is small.

"(4) Each farmer on the great plains whose land is underlaid by this sheet-water at a moderate depth can hope to obtain by pumping water enough to irrigate a small garden and truck-patch, say two to five acres, but:

"(5) The supply is not such as to warrant large expenditures in constructing plants intended to obtain water sufficient for general irrigation. Even if momentarily successful, as a plant would be drawing down the surface of a lake with no outlet, the supply will be exhausted. In other words, the water-surface will be permanently lowered, and disaster to the irrigation-plant will follow.

"These conclusions are reached not only from a consideration of the facts here stated, but also by weighing many other known conditions."

"Sunk wells" are at times formed by the caving in of the surface of the ground, and the consequent exposing of pools of water in a country apparently destitute of moisture. Such cavings are due to removal of soluble material from beneath the crust by the solvent action of the "underflow." Pools of this description have been formed in Western Kansas.*

When the conditions prevailing in the district do not favor

* Senate Doc. 41, part 4, 52d Congress, page 30.

the development of a spring on the side or at the base of a slope, the time-honored manner of tapping the underground supply is to sink the ordinary domestic well into the water-table.

As illustrating what may be expected in the way of a ground-water from a locality beyond the reach of human contamination the following analysis is given of a spring-water from the summit of the Catskill Mountains: *

Free ammonia	.01 per million
Albuminoid ammonia............	.06 " "
Nitrogen as nitrates.............	.01 " "
Nitrogen as nitrites..............	slight trace
"Required oxygen".............	.40 per million
Total solids......................	110 " "

A very good ground-water from Rensselaer County, N. Y., contains:

Free ammonia....................	.0050 per million
Albuminoid ammonia...........	.0075 " "
Nitrogen as nitrates.............	.5 " "
Nitrogen as nitrites.............	none
"Required oxygen"............	none
Total solids....	97. " "

A curious instance of the contamination of ground-water with mineral impurity is reported by Haworth.† In writing of Cherokee County, Kan., he says: "The well- and spring-waters before the mines were opened were first-class, but as soon as the mines were opened all was changed, and the older the mines the worse the water. Animals of all kinds began to be seriously affected."

The mineral deposits of the section of country above re-

* The sample was taken during a prolonged drought.

† *Am. J. Sci.* XLIII. 418.

ferred to consist largely of zinc blende, and the development of the mining properties permits of a ready oxidation of the zinc sulphide to soluble salts. Zinc-bearing spring-water from the neighboring portion of Missouri is reported as containing as much as 327 parts of zinc sulphate per million parts of water.

It is very well known that free sulphuric acid at times occurs in spring-waters of localities where pyrites is exposed to oxidation, and a very celebrated instance of such contamination has already been referred to.

Arsenic is occasionally a constituent of spring-water; and manganese associated with iron is quite common in the ground-waters of some districts, especially Northwestern Missouri. In one water from that section of the country the writer found as much as 9.41 parts of carbonate of manganese per million parts of water. Most instances of the presence of metallic salts in water should, however, be classed under the general head of "mineral waters," and as such are here manifestly out of place.

For the delivery of large supplies the ground-water cannot be conveniently tapped by ordinary dug wells, so that recourse is had in such cases to what is known as "driven wells," set within suitable distance of each other, and coupled to a general main through which the water is drawn by the pump.

Each well is but an iron tube, perforated at its lower extremity, which is driven through the soil to the water-bearing layer below. Single wells of this description, surmounted by a simple hand-pump, may be seen, in some instances, replacing the domestic well in the country door-yard, but the type is more commonly met with in "gangs" of very considerable number for the supply of cities or towns.

A method of sinking them by the use of live steam was

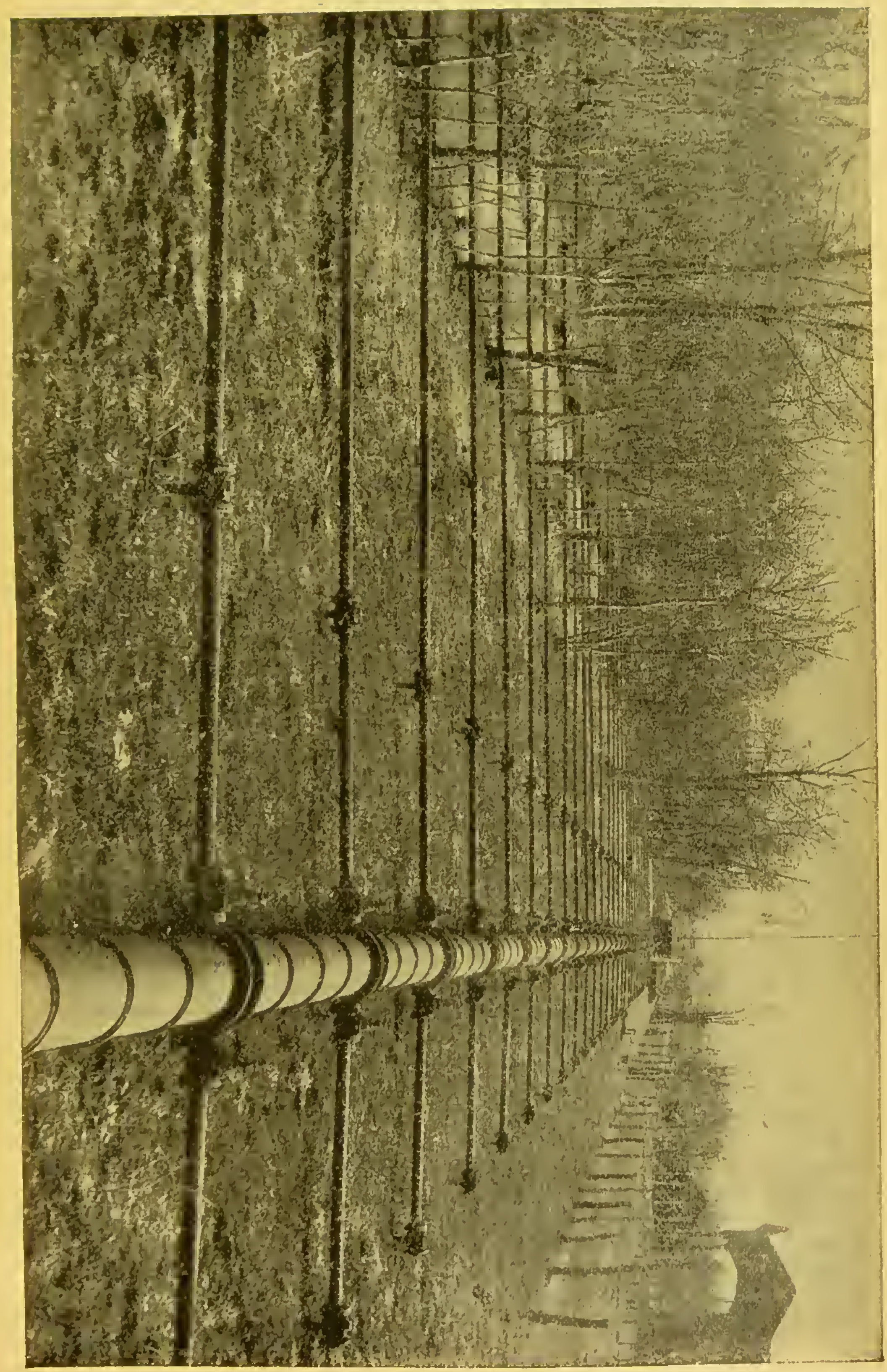
patented a few years ago, and, under some conditions of soil, may show considerable saving in first cost.

A hole some 20 feet deep is first bored with an auger, and in this is inserted a 6-inch heavy galvanized wrought-iron pipe, its lower 6 feet being perforated with $\frac{3}{8}$-inch holes. Inside of this is placed a 2-inch steam-pipe, with a nozzle formed at its lower end, and steam at 150 pounds from a large boiler admitted. Sand, soil, stones, and steam escape from the 6-inch pipe in a continuous stream, and the pipe rapidly descends, being constantly turned by a man with heavy pipe-tongs at the mouth, and extra lengths added as necessary, until a supply of ground-water is found.

By whatever method the "driven well" is sunk, its mode of action is entirely similar to that of the common domestic well, from which it differs only in diameter, and it is supplied by the ground-water of the district in the same manner as its longer known progenitor. There is, in short, nothing gained in the majority of cases from the supposed exhaustion of air by the action of the pump. Much has been claimed under this head, and it has been urged that the zone of influence always widens rapidly under "suction" from an air-tight well; but it must be remembered that "air-tight" is a term which can be usually applied to the well only, and not to the ground overlying the zone of influence. The porous soil will unquestionably admit all the atmosphere required, and consequently the flow of water will be determined by those forces, and those only, which govern in the case of wells of the ordinary type.

When, however, the well passes through an extensive layer of impervious clay, and taps a water-bearing stratum beneath, then the opportunities for a development of the advantages of "suction" reach their maximum.

Brooklyn, N. Y., is partly supplied with water by this system, and the attention of the public is often called to the



DRIVEN-WELL PLANT, BROOKLYN, N. Y.

results obtained there, but it must be borne in mind that the southern half of Long Island * is pre-eminently suited to the driven-well system, it being but a sand-bank thrown up against an old glacial moraine, and that consequently it would not be wise to figure too closely upon such data for general practice. At the first station near the Brooklyn end of the conduit there are 124 wells, each of a diameter of two inches. They are placed in two rows, twenty feet apart each way, and are forty to sixty feet deep. The tubes are perforated for ten feet from the bottom.

During a special trial of these wells the level of the local water-table was lowered eight feet by continuously pumping six million gallons daily for some time. This lowering of ground-water diminished uniformly in proportion to the distance from the wells, and entirely disappeared at two thousand feet away. A few observations were taken at another station where the water was drawn down fifteen feet, and the

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* An investigation as to the extent, depth, and character of the water-horizons underlying Long Island has been made recently by Mr. N. H. Darton, of the U. S. Geological Survey. It has been found that the island is underlaid by many different sheets and streams of water, mainly of relatively restricted extent, and at various depths. They are not as orderly in arrangement as the regular succession of sheets of water which underlie New Jersey and some of the other regions southward, but they are very satisfactory water-bearers, and will be found in greater or less number under nearly every portion of the island. They vary in depth from 20 to 1000 feet or more. The surface of the granite gneiss and other crystalline rocks slopes gently to the south and east, and is overlaid by a great mass of sands, gravels, and clays, which thicken rapidly to the south, so that along the south shore they have a thickness which averages about 1000 feet. These beds are mainly coarse sands and gravels, which are filled with water, but in some areas the finer sands and even clays extend down to the bed-rock, and in these areas no large water-supplies would be found on the bed-rock surface. This was the case in the well at Woodhaven, which was sunk to the granite, at a depth of about 550 feet, without finding water. There may be other areas of this sort, but, in general, wide areas of coarse, water-bearing beds will be found on or very near the bed-rock surface. Mr. Darton has advised the City Works Commissioner to sink wells to the bed-rock before planning to extend the aqueduct system further eastward. (See *Engineering News*, May 30, 1895.)

effect was noticed over a radius of twenty-five hundred feet from the wells.

Great dependence is often placed upon the driven-well system as being an arrangement by which pure water is guaranteed by the thoroughness of natural filtration on a large scale. There is one weak point in this view which must be always kept in mind and guarded against. The filter is a good one without question, but if damaged it is beyond repair and should be treated with corresponding care. The danger is that an additional supply is frequently sought for by an increase in pumping capacity rather than by an extension of the plant. As a result the wells are over-forced, there occurs undue lowering of the local water-table, rapid flow of water towards the exhausted locality causes channelways to form in the subsoil, and surface-water consequently enters the wells without suitable purification. Such a condition of things being once established, no remedy is available.

Writing about a large city plant, Breneman says: "Seven million gallons of water are daily drawn from a system of 100 wells, varying in depth from 45 to 100 feet, and covering a line about 400 feet in length. Such a yield corresponds to a total rainfall of 32 inches a year upon 3000 acres,

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A very unusual form of well-plant is to be seen at Frankfort-on-the-Main, Germany. About six miles from the city there has been constructed a brick-lined tunnel, some forty or more feet below the soil-surface of a pine forest. This tunnel is considerably over a mile in length, and its level is about that of the upper surface of the ground-water. Through its bottom a large number of tubed wells pierce the ground to the further depth of about forty feet, and the water pumped from them is carried by a common main laid upon the bottom of the tunnel.

South Haven, Mich., is supplied with water from wells, which are driven very nearly horizontally under Lake Michigan. Such an arrangement is to be resorted to when the water is to be drawn from underneath a watercourse whose bottom is a thin layer of sand supported by a substratum of impervious material. (For cut see *Engineering Record*, May 20, 1893.)

or, roughly, represents the same annual rainfall upon all of the land within a radius of $1\frac{1}{4}$ miles from the pumping-station. Owing to the sudden demand for this water the soil-waters must be continually drawn downward in the vicinity of the pumps, and the nearer regions must be more effectually drained than the more remote. The predicted consequences are abundantly realized. Shallow wells in the neighborhood are wholly or nearly dry since the pumping-station has been opened. A swamp, formerly existing about the station, has been dried up. The subsoil of a cemetery, 370 yards distant, which offers frequent opportunities for observation, is said by the sexton to be much drier than heretofore."

A fact often lost sight of is that driven wells, so far as a permanent supply is concerned, are dependent upon the amounts of rainfall, "run-off," evaporation, and plant requirements. There is not, contrary to popular conception, an underground reservoir from which unlimited quantities of water may be pumped. It is true that a reserve storage exists, that may be drawn upon in time of drought, but Nature keeps a strict account of such matters, and the deficiency created in time of need must be made up during the period of plenty; otherwise the delivery of the plant will gradually diminish and ultimately entirely cease.

The result of heavy pumping was shown by the determinations of chlorine in the water from the old Liverpool wells. Lowering of the water-table, with infiltration of salt water from the River Mersey, was indicated, and at the same time evidence was presented, if such could possibly have been desired, that salt cannot be removed from sea-water by percolation through sand. (See page 290.)

Galveston, Tex., had a very expensive experience, showing the inability of sand to freshen sea-water. The citizens of that town attempted to extend an excellent driven-well

plant which they possessed by increasing the number of wells, and they carried the draught upon the ground-water beyond the point of normal supply. As a result the entire system was damaged by the inflow of salt water from the Gulf.

One very material advantage possessed by a driven well over a dug one is that it can be sunk deeper in the water-bearing sands at small expense, and, with a long strainer, can take water throughout a great fraction of its length. A dug well, on the other hand, has its construction hampered after water is reached, and its cost per foot is greater beyond that point; so that it commonly has to depend principally upon its bottom for supply, tapping, as it does, only the upper portion of the ground-water layer.

When preparations are being made to sink a gang of driven wells, consisting of a considerable number of individuals, one of the first questions that must be considered is the distance apart the wells should be placed so as not to draw from one another's territory. This is a point upon which no fixed rule can be given. In the Brooklyn plant, to which reference has been made, the wells are twenty feet apart, but the local conditions may cause this distance to be materially increased in some cases. It is often poor economy to place wells nearer than fifty feet from each other, and at times even one hundred feet may be the suitable distance.

A good practice to follow would be to sink two wells at what judgment would indicate as a proper interval, pump from one of these, and, if the second be too much affected by such pumping, increase the distance for the third well, and so on until the proper distance be determined.*

* One of the engineers whom Mr. Hazen met prospects for underground supplies in an interesting manner. He puts down three wells, located at the three points of an equilateral triangle, and from the relative heights of water in

Closely related to the well systems already spoken of, the "infiltration-gallery" stands as a widely used method for securing the water of the ground.*

Such a gallery is really but a dug well with one very long horizontal axis. Its position is usually near, and parallel to, the banks of some stream, such a site being chosen with a view of securing its supply from the water of the river. Except under exceptional circumstances, however, the water reaching the gallery comes from the landward side, and is the ground-water of the district for which the river is the drain.

Rivers may indeed diminish in volume as they flow onward, and may even entirely disappear by sinking into the ground, as is the case with a number of streams flowing down the slopes of the Rocky Mountains, but this condition is distinctly exceptional. A river is commonly to be considered as a drain, into which water is received, but from which none flows. To such an extent is the bed of a river usually rendered impervious to the outward passage of water by the accumulation of fine silt that an old authority quite covers the case when he says: "If you dug a well in the middle of a river, and kept out the surface-water, it is doubtful if you would get the river-water in your well."

The writer found the following results for water from a well sunk upon a sand-bank in a river, and for water from the river itself: †

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the wells deduces the direction of the underground flow. The velocity of the flow is tested by putting salt in one of the wells and testing the times and amounts of increase in chlorine at the well lower down. This engineer had no confidence in pumping tests to determine the permanent yield of wells.

* See page 177.

† The well-water formed adherent boiler-scale, and that from the river did not.

	River.	Well.
Free ammonia	.045	.045
Albuminoid ammonia	.155	.095
"Required oxygen"	6	2.7
Chlorine	2.9	4.3
Nitrogen as nitrates	.337	.127
Nitrogen as nitrites	0	0
Total residue	131	100.5

Mr. Denman, in speaking of some very successful galleries at Des Moines, says:

"We are favored by nature in being able to take water from the valley of the Raccoon, which is surrounded on either side by high hills, not less than one hundred and fifty feet high; and in the valley there is sand and gravel of great depth.

"We adopted years ago the gallery system with a great deal of success, and our supply of water is only limited by the expense of getting at it. At present we are engaged in the construction of filter-galleries, having added about twelve hundred feet to our original and former system.

"We do not perceive any of the river-water in the supply in our galleries, although they are laid in the middle of the river. When the section of gallery was crossing the river, looking inside we failed to detect any water dripping from the top, although the river was flowing over it and only twelve feet above. The water from the galleries is much colder than that from the river."

A plan for the supply of Pittsburg has been recently suggested, and is substantially as follows: *

"The Allegheny River has the immense watershed of over 10,000 square miles above Pittsburg. Underneath its bed is a gravel deposit from 40 to 50 feet in depth. A large number of wells in the neighborhood of Pittsburg have been

* *Engineering News*, January 4, 1894.

sunk along its shores, and they have uniformly yielded large amounts of water. The wells sunk along the shore have produced hard water, unfit for boiler purposes, but it may be that the ground-water under the centre of the stream is soft.

"For galleries depending largely upon a supply from the river there is suggested a series of flumes at least 15 feet wide and 4 feet high, made of wood and sunk into trenches dredged transversely in the bed of the stream. These should be placed as far apart as possible and should lead into a collecting-gallery placed parallel to the stream. As a precaution against silting a stand-pipe should be constructed whose contents could be emptied at will into any one of the infiltration-galleries. In order to reduce the probability of tapping the ground-water and to avoid the necessity of softening the flumes could be placed in one of the numerous riffles of the Allegheny at a depth of about 10 feet below low water.

"With the coarse gravel found in the bed of the Allegheny a rate of infiltration of 300 gallons per square foot per day can be safely assumed, so that for a supply of 30,000,000 gallons per day 100,000 square feet of area would be required. This can be obtained with seven galleries 15 feet wide and 900 feet long."

It is greatly to be doubted if the proposed device would furnish river-water, if the depth of the dredged trenches were at all considerable; and as the local ground-water is admittedly unsuitable, the same objection would, of course, apply to water from under the river-bed that is advanced against that secured from wells driven along the banks.

The danger of silting, referred to by the author of the above plan, is certainly a very notable one, and the probability of its occurring should be ever kept in view by the users of infiltration-galleries, filter-cribs, and driven wells.

As an instance of the silting up of a gallery no better illustration can be given than the present nearly waterless

condition of the city of Florence, Italy. The expensive tunnel will probably have to be abandoned, and a new supply of surface-water introduced from the neighboring mountains. The suggestion above made of a stand-pipe, from which a reversed current could be instituted in the event of silting, would probably work better in so open a structure as the one proposed than in a closed subterranean gallery or in driven wells; but a reversed current so often fails in freeing a clogged well that we must confess to being somewhat pessimistic about the general reliability of the method.

Dependence is constantly laid upon the excellent filtering powers of these underground galleries, and they justify it during the earlier periods of their use, but, considered as a filter, such a device is beyond cleaning and repair; it may clog, or, on the other hand, ruinous channelways may follow heavy pumping. In the first instance no water, and in the second instance polluted water, may result.

As concerning the question of pollution of ground-water, an important paper was recently read and discussed in London on the influence of different kinds of soil on the cholera and typhoid organisms. The following is taken freely from the report: *

"The research was undertaken with a view to answering the following question: Had the soil in itself any action favorable or injurious to the life of the comma spirillum of *cholera Asiatica* and the bacillus of typhoid fever, or did the length of life of these organisms in soil simply depend upon the amount of moisture that might be present? The action of the saprophytic bacteria present in the soil was left out of consideration. Sterilized soils alone were used. The experiments were carried out with white crystal sand, yellow

* *Medical Record*, June 23, 1894.

sand, garden earth, and peat. These were sterilized by means of moist heat. In white crystal sand comma spirilla were alive on third but dead on fourth day; in yellow sand, alive on third but dead on fourth day; in garden earth, alive on third but dead on fourth day. The comma spirilla must have died, therefore, between the third and fourth days. Experiments were next made with a moist soil, which, however, contained no excess of moisture. In moist white crystal sand comma spirilla were alive on the seventh day; in moist yellow sand comma spirilla were alive on the thirty-third day; in moist garden earth they were alive on the thirty-third day.

"Experiments were made to find the length of time comma spirilla would live in a soil when any excess of moisture was allowed to pass through the soil, but where little or no loss of moisture took place from the surface. Under such conditions the spirilla were alive in white crystal sand on the twenty-eighth day, in yellow sand on the sixty-eighth day, and in garden earth on the sixty-eighth day. In a soil deprived of its moisture the comma spirilla did not live longer than one to two days. In white silver sand, when moisture was allowed to escape, the spirilla were alive on the third day, but dead on the eighth day; but if evaporation of water was prevented the comma spirilla were alive on the forty-seventh day. In white crystal sand, where evaporation was allowed to take place, the spirilla were still alive on the twenty-seventh day with 1.57 per cent of moisture in the sand. The spirilla were dead on the thirtieth day with 0.66 per cent of moisture in the sand. When evaporation was prevented, the spirilla were alive on the one hundred and seventy-fourth day, and the sand still contained 7.1 per cent of moisture, showing a close relation between the amount of moisture in the soil and the length of life of the organisms. With regard to peat, it was found that the

comma spirilla were invariably dead in twenty-four to twenty-six hours, independently of the amount of moisture that might be present.

"Next as to the bacillus of typhoid fever on a dry soil where evaporation was allowed to take place: In white crystal sand the bacilli were found up to the ninth day, in yellow sand up to the eighteenth day, and in garden earth up to the fourteenth day; but in moist crystal sand the typhoid bacilli were alive on the twenty-third day, in yellow sand and in garden earth on the forty-second day. On soils which had been deprived of their moisture the bacilli were only found up to the seventh day.

"Experiments made with peat showed that on this soil the bacilli did not survive longer than twenty-four hours. Peat was the only one of the four soils used which exercised a distinct destructive action on the organisms, independently of the amount of moisture present. Experiments made to test the filtering capacity of the soils showed that with a filter six inches thick white crystal sand held back 99.6 per cent comma spirilla, yellow sand held back 99.9 per cent comma spirilla, garden earth held back 89 per cent comma spirilla, and peat held back 100 per cent comma spirilla. On the other hand, a current of water could carry the comma organisms through two feet and a half of porous soil. Conclusions: White crystal sand, yellow sand, and garden earth had no marked action on the organisms—their length of life in the soil depending chiefly on the amount of moisture. Peat, on the contrary, was very deadly to both the comma spirillum and the typhoid bacillus. The soil acted as a good filter, holding back most of the organisms; but it was possible for them to be carried through two feet and a half of porous soil by a current of water."

The action of the common saprophytes in the soil is known to be prejudicial to the growth of the cholera germ,

and, as these ordinary bacilli are more plenty in the upper layers of the soil, it is interesting to note the observation of Sternberg that "the cholera spirillum in the months of August, September, and October grew at a depth of nine feet in the soil, but in the remaining months of the year failed to grow at six feet, although growth occurred at four feet."

This seems somewhat of a contradiction, unless it be meant that the spirillum fails to reach the stated depth after passing through the upper soil-layers.

Sternberg also found that the bacillus of typhoid fever "grew at a depth of nine feet during the greater portion of the year."

The opportunity for the contamination of well-water, particularly that of the common domestic well, is often very great. No proper conception of the right location for the house-well ever seems to enter the minds of most of our rural people, and if water can be had from a spot conveniently near for general housework inquiry as to the quality of such supply is usually considered quite superfluous. The author has elsewhere referred to an instance where the well was entirely covered by a huge manure heap.

In their Sixth Report the English River-pollution Commission state the case quite graphically:

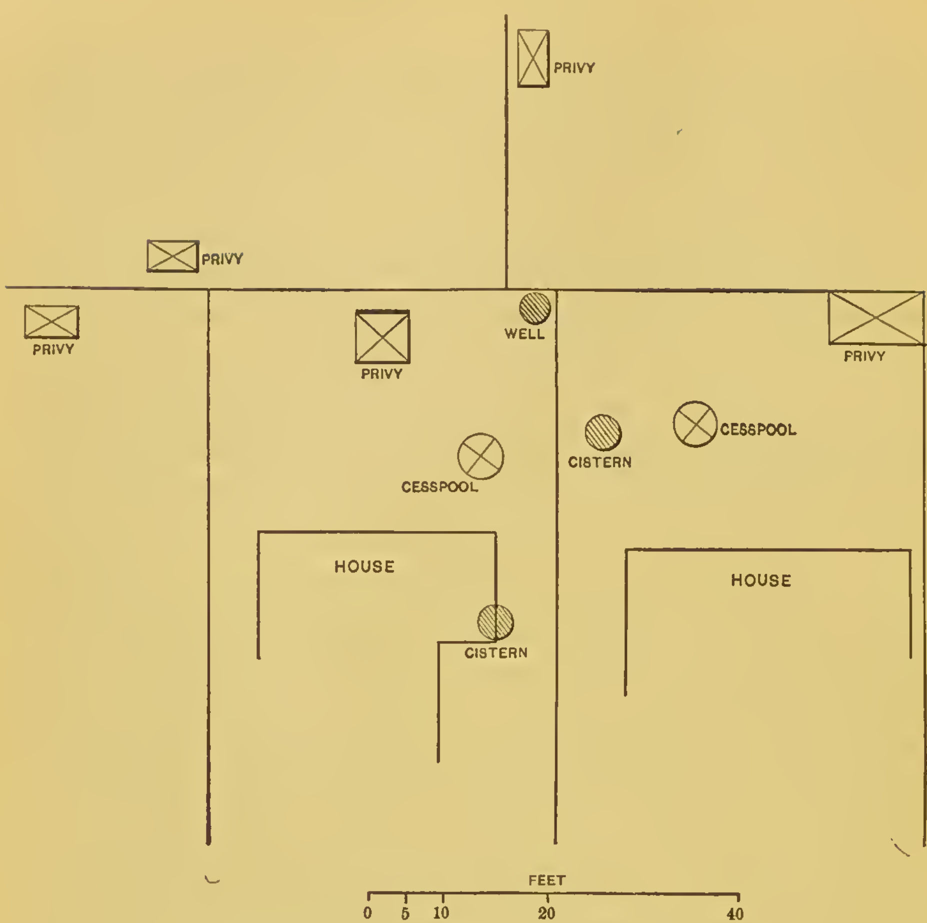
"The common practice in villages, and even in many small towns, is to dispose of the sewage and to provide for the water-supply of each cottage or pair of cottages upon the premises. In the little yard or garden attached to each tenement or pair of tenements two holes are dug in the porous soil; into one of these, usually the shallower of the two, all the filthy liquids of the house are discharged; from the other, which is sunk below the water-line of the porous stratum, the water for drinking and other domestic purposes is pumped. These two holes are not infrequently within

twelve feet of each other, and sometimes even closer. The contents of the filth-hole or cesspool gradually soak away through the surrounding soil and mingle with the water below. As the contents of the water-hole or well are pumped out they are immediately replenished from the surrounding disgusting mixture, and it is not, therefore, very surprising to be assured that such a well does not become dry even in summer. Unfortunately excrementitious liquids, especially after they have soaked through a few feet of porous soil, do not impair the palatability of water, and this polluted liquid is consumed from year to year without a suspicion of its character, until the cesspool and well receive infected sewage, and then an outbreak of epidemic disease compels attention to the polluted water. Indeed, our acquaintance with a very large proportion of this class of potable waters has been made in consequence of the occurrence of severe outbreaks of typhoid fever amongst the persons using them."

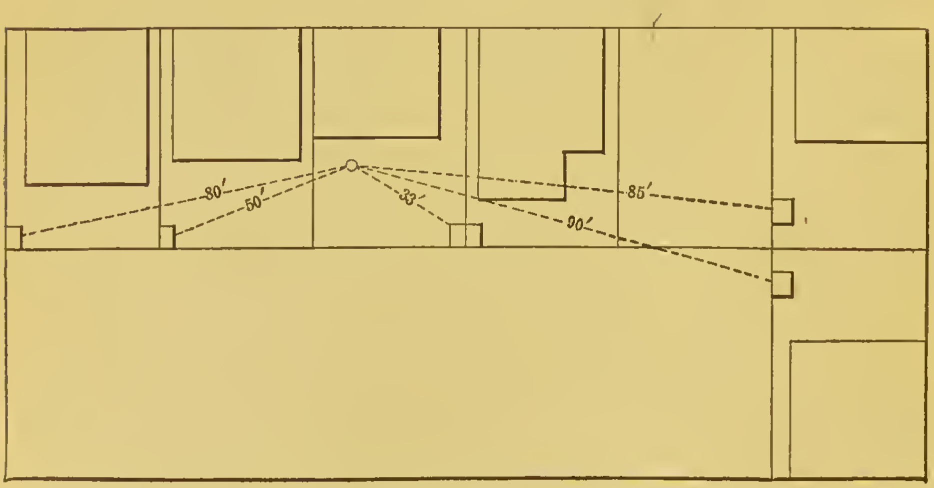
The reckless manner in which a domestic well is frequently surrounded by sources of great pollution is here shown in an illustrated form from a Rhode Island case reported by E. W. Bowditch. (See top of page 312.)

Although not so aggravated an instance as the above, yet the following case is sufficiently bad to justify hearty condemnation. The well, which, with its surroundings, is shown in the following plan, is on Green Island, N. Y., and its water, which is in daily use, is doubtless responsible for the typhoid fever occurring in the neighborhood. The water-table slopes toward the well. (See bottom of page 312.)

The analytical results of this water show very low "ammonias," but exceedingly high "chlorine" and "nitrates," adding further weight to Mallet's decision that a knowledge of the amount of "nitrates" is especially valuable for arriving at a correct judgment as to the quality of a water:



WELL SURROUNDED BY PRIVIES—RHODE ISLAND.



WELL AND SURROUNDINGS—GREEN ISLAND, N. Y.

Free ammonia	.01
Albuminoid ammonia	.02
Chlorine	70.00
Nitrogen as nitrites	trace
Nitrogen as nitrates	15.00
"Required oxygen"	.10

A well at Highland Falls, N. Y., twenty feet in depth, said to furnish "very excellent water," is some sixty feet distant from a privy in one direction, and the same distance from a graveyard in another. One public well, which the author succeeded in having closed after much difficulty, was fouled by cesspool infiltration to a large extent, yet because of the coolness and sparkle of its water it was widely popular, so much so that its final closing had to be accomplished after midnight to avoid resistance.

As an instance of excessive pollution the following analysis is given of a well-water from Southampton, England.* The water was "in daily use for all domestic purposes, was fairly presentable to the eye, and not unpalatable. Under the microscope it showed starch-grains, paper, and animal hairs."

Free ammonia	56.800
Albuminoid ammonia	.332
Nitrogen in nitrates	19.026
Chlorine	22.000
Phosphates	heavy traces
Total solids	417.000

Unattractive as this English picture is, we can certainly match it in America; and in some cases the unsanitary arrangements causing the trouble receive more or less support from the law.

In many of the towns of Ohio the local boards of health

* *Analyst*, VI. 65.

determine the minimum distance to be allowed between a well and an uncemented privy-vault, and such distance is most commonly fixed at fifty feet. The permitted distance for the town of Norwalk, a place of 8000 inhabitants, is twenty-five feet. At Bond Hill the minimum distance allowed is twenty feet! *

That any such distance of soil-filtration can protect a well from pollution, provided the polluting source be constant in character, is beyond even hoping for, and many instances could be given showing how even considerably greater distances have also failed.

Extract is here made from a report of the writer's upon the question of closing certain city wells:

"As is well known, there are a number of street pumps in this city, and the water which they supply is cool, sparkling, brilliantly clear, and generally relished. The ground

* See Report Ohio Board of Health for 1892.

F. O. Driscoll writes as follows to the *Century Magazine* concerning the city of Canton, China:

"The street paving was of loose granite slabs laid crosswise, about nine inches broad and six inches through, and as long as the street was wide. Although presenting a somewhat irregular surface, the face of each slab was generally worn smooth by the treading of unshod feet. A drain ran down the centre of each street, under the granite slabs, into which, between the joints, percolated rain-water, fluid refuse, and house-slops. These liquids ran out into the main tidal canals which intersected the city, and when they did not run, as was not infrequent, the slabs were raised, and the drains cleaned out.

"The water supply of the city is entirely drawn from wells. So far as I could see there was one to each house. These wells were merely round holes about fifteen inches in diameter cut in a granite slab flush with the floor, and provided with a small bucket fastened to a bamboo for drawing the water, which appeared to be never more than from four to six feet below the well-stone. I imagine that the absence of continual diphtheria and typhoid fever, which such a water-supply naturally suggests, may be accounted for by the fact that fecal matter is not permitted to accumulate in the city, and that little, if any, water is drunk which has not been previously boiled. Then the fact of the houses being always open must of course insure their thorough ventilation."

The fact that human excrement is always collected in jars and sold for manure is perhaps a reason for typhoid fever being less common than one would expect from such insanitary conditions.

into which these wells are sunk is the old river flood-plain, which extends from the present river to the eastern hills. Into this same soil pours the drainage from many cesspools and privies, and the slope of the ground in the centre of the city being away from the river, the natural drift of the ground-water toward a western outlet is to an extent impeded. In consideration of these few facts, can any reasonable person expect to get pure water from such a source ?

"It is a fatal error to fancy that because a water has a bright, sparkling, clear appearance and a pleasant taste therefore such water is wholesome. Carbonic acid gas is what causes the brilliancy and refreshing taste of a ground-water, and to the solvent action of that gas is due the clearness of many waters which hold much organic matter in solution. When it is borne in mind that carbonic acid is one of the products of sewage decomposition, the inference as to its possible source in the case of the present well-waters is not a pleasant one. During the last four years I have at different times examined the waters from several of these wells, and am persuaded that they are contaminated with sewage material beyond a peradventure.

"It is hopeless to depend upon the purifying influence of the intervening soil to protect the wells from privy and cesspool fouling, because soil-filtration, in order to be effective, must be *intermittent.* That is, after a 'dose' of sewage has been added to a soil (and the 'dose' must not be a large one) opportunity for thorough aeration of the soil must follow, or the second 'dose' cannot be purified. With a constant flow of polluting material the purifying powers of the soil quickly cease to act.

"It will be objected that these well-waters have been in use for many years without bad results following. Possibly; but it must be remembered that the imbibition of sewage derived from healthy sources may be quite harmless unless

it be in too concentrated a form, however undesirable it may be from an æsthetic standpoint. This has been experimentally proven many times. The serious part of it all is that the sewage which contaminates the well-water may, during an epidemic, suddenly become pathogenic in character, and then the well becomes a distributing centre for disease. It may be that there are wells in this city and vicinity free from sewage infiltration, but it is certain that there are others not so fortunate. A city well is always to be suspected, and if, upon examination, its water is found impure, it should be forthwith ordered closed, particularly under circumstances such as threaten cholera invasion. The well-known case of the spread of the cholera in London by the use of well-water during the last epidemic is a special warning."

As illustrating how unexpectedly a good ground-water may become damaged on its way to the point of consumption a case recently observed by the writer while in New Jersey is worthy of mention. The well was found in good location and furnishing excellent water, but the pump-main was laid to the house by way of a somewhat distant stable, on top of which was the windmill supplying the power necessary to raise the water. The objectionable analytical results were found, upon investigation, to have been due to defective pump connections and infiltration of stable drainage.

A few months since the Medical Society of the District of Columbia submitted to the House of Representatives a valuable report, with numerous charts, showing the prevalence of typhoid fever in the capital and its relation to the use of water from the street wells.

"We know that water from the 310 pumps existing at the time of the report of 1889 was largely used by the people living on the 426 squares in which the 626 fatal cases oc-

curred. Even by those having access to Potomac water, well-water is largely consumed, on account of its being colder during the hot months of the year."

The committee of the medical society having the investigation in hand divided the city arbitrarily into five sections, and then found the following relations existing between the number of street wells in use in each section and the corresponding number of fatal cases of typhoid fever: *

Deaths from Typhoid.	Number of Wells.
197	140
179	70
114	34
84	47
52	18

To obtain the approximate number of total cases of illness from typhoid the number of fatal cases should be multiplied by ten. The relation shown in the above figures is quite striking.

It would not be amiss, perhaps, to refer to another point strongly illustrated in the Washington report above quoted, but before giving the numerical data the report contains the reader is asked to bear in mind what has been said in another chapter concerning the recent investigations of Sanarrelli, which point to a relation between bad hygiene and susceptibility to typhoid fever.

This work of Sanarrelli's is of great importance as filling a gap long felt, and harmonizing to a great degree the hitherto opposing theories of "ground-air" and "water-supply" as causes of typhoid fever. As so often happens, the middle course has proved the correct one, and the two theories are

* In this connection see also "Analysis of Washington Well-water," by Richardson, *J. Anal. Chem.* v. 23.

found to be complementary rather than in opposition. Pettenkoffer's "ground-air" introduces the insanitary conditions suited to the speedy development of the typhoid germ should it arrive with a contaminated water-supply. The Washington report lays special stress upon the fact that good water and good sewerage should go hand in hand if typhoid is to be avoided, and in the light of what we know to-day the point is unquestionably well taken. (See page 319.)

The city of Dantzic received its good water in 1869, but the typhoid death-rate was not materially improved until 1872, when the city was sewered. Vienna showed the opposite condition; an excellent sewerage system, but a bad water-supply, had existed previous to 1874, and the annual typhoid death-rate ran as high as 34 per 10,000 of population. In 1874 water of very superior quality was introduced, and in three years the typhoid rate had fallen to 1.1. We thus see that good sewerage alone is not all that will be required for desirable sanitary results.

"In Munich from 1854 to 1859, when no means existed to prevent the fouling of the soil, the mortality was 24 to 10,000 inhabitants. From 1860 to 1865 the sides and bottoms of the pits of the privies were cemented, and the mortality fell to 16.8. From 1866 to 1873, with partial sewerage, the rate was 13.3; from 1874 to 1880, with improved sewerage, it was 9.26; and from 1881 to 1884, with still greater improvements, it fell to 1.75 per 10,000 inhabitants.

"Typhoid fever increases in proportion to the saturation of the soil with decomposing organic matter, especially human excreta, and to the drinking of infected well-water.

"Typhoid fever decreases in proportion as a city is well sewered, and in proportion to the abandonment of the drinking of well-water* and of all contaminated water."

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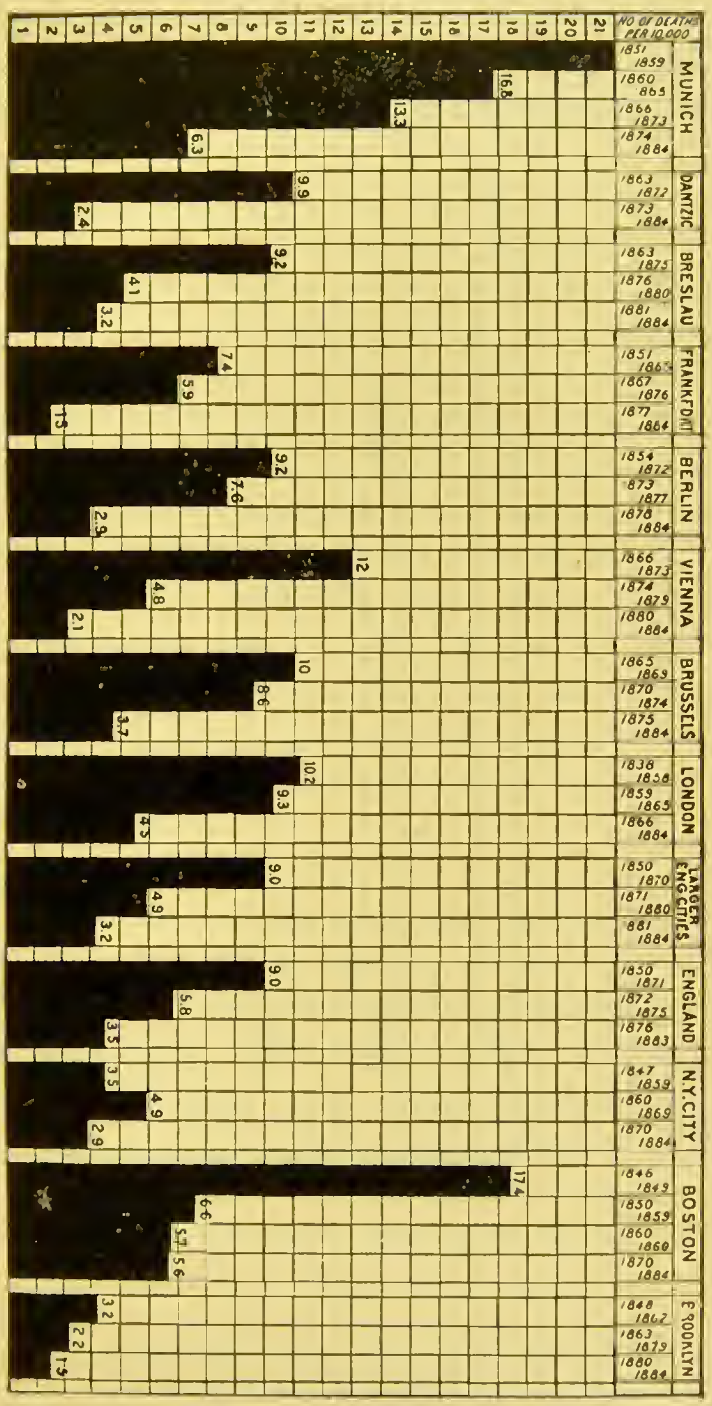
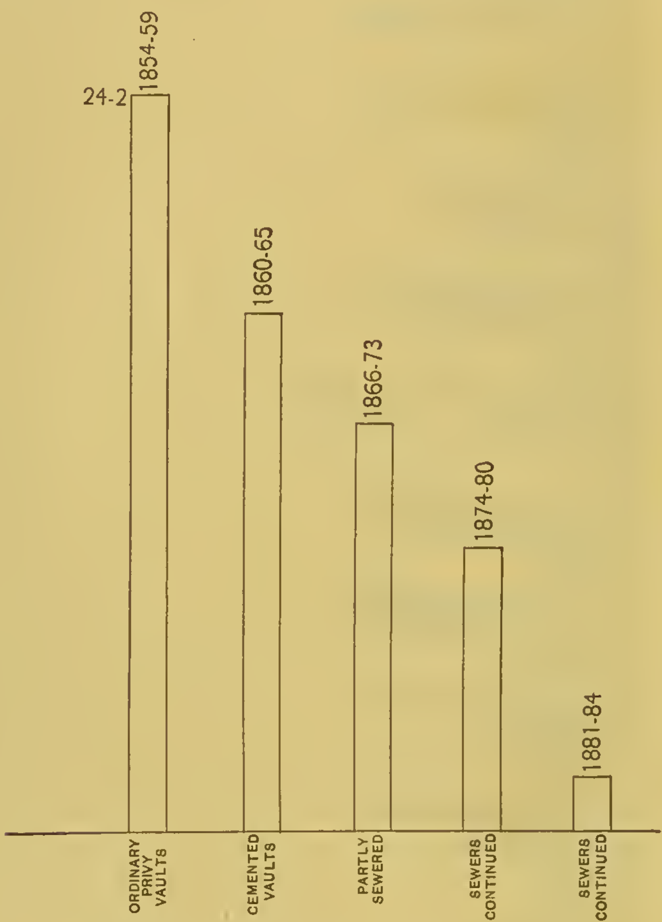
* City well-water is of course intended.



DEATHS FROM TYPHOID FEVER TO EACH 10,000 INHABITANTS BEFORE, DURING, AND SINCE THE INTRODUCTION OF SEWERAGE AND WATER-SUPPLY. (AFTER E. F. SMITH, MICHIGAN STATE BOARD OF HEALTH.)

These are the carefully considered conclusions of the Washington committee, after a very painstaking investigation, and they are graphically supplemented by the following chart, which abundantly explains itself:



CONDITIONS OF SEWERAGE AND TYPHOID FEVER DEATH-RATES (PER 10,000 INHABITANTS) AT MUNICH. (AFTER BAKER.)

In view of his general observations and experience the author is strongly of the belief that seepage from the privy-pits into the domestic well is the cause of typhoid fever being largely a country disease; and he is interested in the passage of a law doing away with such vaults entirely. Some means of frequent removal of excrement, either by burial in

safe and successive spots, as is possible upon a farm, or by transportation to a distance, as can be arranged for by a country town, should be insisted upon by law. Economy of both purse and labor is now accomplished by virtually depositing all such material in the family well.

"In order to ascertain to what extent soil was contaminated by privy-vaults I dug down near a privy-vault which was situated on the outskirts of the town and isolated, so that there were no other known sources of contamination around; I dug down a foot behind this privy-vault and took up some soil three feet below the surface to determine the amount of organic matter in it; then I went off 6 feet and did the same thing, then 12, then 18, then 24, then 30; and, without going into detail, suffice it to say that the contamination of the soil from that single privy, built upon nearly level ground, could be detected 50 feet from the vault plainly. This was determined by comparing the amount of organic matter in these different samples of soil with other soil of the same kind where there were no known sources of contamination." *

An excellent way to determine the probability of objectionable drainage material entering a well is to place a quantity of a solution of common salt, of lithium chloride, or of fluorescein ($C_{20}H_{12}O_6$) at the point whence contamination is supposed to come. The normal composition of the water being known, there will appear an increase in "chlorides," a spectroscopic test for lithium, or a decided fluorescence in the water if there be drainage from the source in question.

* Vaughan, Ypsilanti Sanitary Convention, July, 1885.

CHAPTER IX.

DEEP-SEATED WATER.

SPRINGS of small flow, such as trickle out of the country hillside, are properly classified with the shallow wells already spoken of; they furnish "ground-water" only and are of local origin.

Quite another matter, however, are those natural fountains which reach the surface in very great volume, possessed of a temperature radically different from that of the local subsoil, and holding in solution mineral materials that may be quite foreign to the neighborhood. Such water is always of distant source, and the gathering-grounds where it originally falls as rain may be very far away indeed.

Picture the outcrop upon some rainy upland of a porous stratum, encased upon either side by strata impervious to water; let the strata be possessed of a moderate dip, then let them be cut transversely at some point below, either by simple erosion or by a geologic fault, and the conditions for a deep-seated spring would be complete. Rain-water falling on the distant outcrop would pass down the porous stratum, picking up soluble material on the way, and would escape as a spring at the point where the strata were broken or eroded.

Very notable springs due to geologic faults occur with frequency, but to Americans the best-known instance is to be found at Saratoga, although the water furnished is medicinal rather than potable, and therefore beyond our present consideration.

At the head of San Antonio River, not far from the city of San Antonio, Tex., is situated a mammoth spring of pure water, whose daily outflow is some fifty million gallons. This spring is but one of a group of great springs which "coincide almost exactly with the line of the great Austin Del Rio fault." *

A very curious instance of a spring of great magnitude caused by erosion cutting across the water-bearing stratum is to be found several miles out at sea off the coast of Florida, east of Matanzas Inlet.†

There are several other springs on the same coast similar to this, although not so large.

A shipowner familiar with the locality informs the writer that the volume of water boiling up in the ocean at the site of the Matanzas spring is so large as to prevent a boat remaining on it for more than a moment, as "the boat is washed off from it as from the rapids of a river." The same authority describes the odor of the water as that of a sulphur spring, which is an additional point showing its kinship to the artesian waters of Jacksonville and St. Augustine.

Fresh-water springs occur in the North Sea in the vicinity of the islands surrounding Holland, and are situated two or three miles from shore. "Similar springs may be found in the Adriatic Sea, near Fiume, Abazzia, Triest, and in other places, so that the surface of the sea is slightly raised up and a whirlpool may be observed." ‡

Instances are by no means rare of the use of deep springs

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* Senate Doc. 41, 52d Congress.

† There are some reasons for believing that the Matanzas spring is not caused by simple erosion, but rather by a bursting of the confined waters through a hole in the upper hard rock-layer. Successful sounding has not been accomplished in the spring itself, but in its immediate vicinity the ocean suddenly deepens from a depth of 60 to one of 120 feet.

‡ Am. Soc. C. E. xxx. 300.

for water-supplies of magnitude,* but deep-seated water is much more commonly reached by special borings.

It would be going too far to undertake a description of the process of drilling these deep wells, yet there are certain facts concerning their cost and rapidity of construction, given us by Professor Carter,† which may properly be here inserted:

"The most difficult rocks to drill through are trap, quartzite, compact fine-grained sandstones, certain clay slates, granites, syenites, and compact hornblende schist, obsidian, etc.

"The softer rocks, such as talcose and chlorite schists, serpentine and other magnesian rocks, limestone, dolomite, hydro mica schists, and many coarse-grained sandstones, are readily drilled through. The following table will show the thickness of rock pierced by a chisel drill 20 feet long, $5\frac{5}{8}$ inches in diameter, weighing 700 pounds, guided so as to make a round hole:

Locality (Pennsylvania).	Rock.	Rate.		
Duffield's farm, on Stony Creek, near Belfry,	Clay slate (Trias)	$4\frac{1}{2}$ ft.	drilled in	10 hours
Ice company's well, Norristown	Sandstone (Trias)	5	"	"
Kunkle's farm, Valley Green Road, near Flourtown.....	Limestone (Silurian)	$5\frac{1}{2}$	"	"
Wheadley's farm, Chester County.	Hydro mica schist	7	"	"
Wm. Janeas' farm, near William Station.. ..	Sandstone (Potsdam)	10	"	"
Roberts' well, Spring Mill....	Sandstone (Potsdam)	$18\frac{1}{2}$	"	7 hours

"The minerals which compose a rock may be very hard, and yet the cementing material may hold the grains so loosely that the drill will make rapid progress through the rock. Sandstone, when composed entirely of silica, or when the

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* The "Vanne" water, supplying a part of Paris, comes from springs in massive chalk near Troyes. The daily flow is 96,000 cubic metres (25,344,000 U. S. gallons). Part of this flow comes from three high springs emptying directly into the conduit, and the rest from a dozen lower springs the waters of which have to be lifted by pumps.

† *J. Fk. Inst.*, September, 1893.

cementing material is gelatinous silica, as in quartzite, is extremely hard to drill, but when the cement which binds the grains is feldspar, which decomposes readily, then the grains are loosely held, and the rock is readily drilled.

"The price of drilling is about $2 per foot in Montgomery County, Pa., for wells six inches in diameter and from 100 to 200 feet deep; this is independent of the character and hardness of the rock.

"Other contracts in Philadelphia have been made at the rate of $2.75 per foot for drilling down to 500 feet, and $3 per foot for drilling below a depth of 500 feet; this does not include the iron pipe for casing, but only the drilling. The six-inch iron pipe (internal diameter five and five-eighths inches) which is used to line the well varies in price from forty to fifty-five cents per foot."

To the foregoing statements of Professor Carter it would be well to add that the presence of boulders, as in a glacial drift, very greatly increases the trouble and expense of well-boring.

Wells are sunk through the shales and conglomerates of the Catskill Mountains, but not to great depths, at the rate of $2 per foot, and in the Hudson River shale of the upper valley at from $1.50 to $2 per foot. In the oil regions of Pennsylvania the average price is about $1 per foot for the boring alone.

"In Europe the various deep bore-holes range in the following order:

	Feet.
Domnitz, near Weltin, Germany	3287
Probat-Jesar, Mecklenburg	3957
Sperenberg, near Zossen	4173
Unseburg, near Stassfurt	4242
Lieth-Elmshorn, Holstein	4390
Schladebach	5735

"The Schladebach well was drilled under the supervision of the Prussian government, in search of coal. It appears that the total cost of drilling the well was $53,076, or at the rate of about $9.25 per foot of depth. The average daily rate of boring was 4.59 feet. The initial diameter of the hole is a little over 11 inches, and the least diameter in the lowest section is about 1.3 inches. Temperature observations which were made showed that at a depth of 5628 feet the temperature was 133.8 F.* Further work on this well has been abandoned."

The expression "artesian" has been extended to include deep wells under all conditions, but without proper license, because the term originally came from the name of the French province where deep wells were first successfully established, and such wells were "flowing." It is therefore to "flowing wells" only that the expression "artesian" properly attaches.† Whether, however, the well be a flowing one or one from which the water has to be raised by power, the conditions governing the storage of such water are essentially the same as have been already given when speaking of deep springs. An outcrop of a porous stratum in a rainy upland acts as the collecting area; this stratum is of moderate dip and is enclosed by other strata, impervious to water, lying above and below.

Unless the strata form a basin or pocket the water of the porous layer will find its natural outlet in spring form where the layer is cut transversely by erosion or fault; but should a well be sunk at some intermediate point the water will rise in the same, or overflow, to a degree dependent upon the head to which it is subjected; that is, to the ele-

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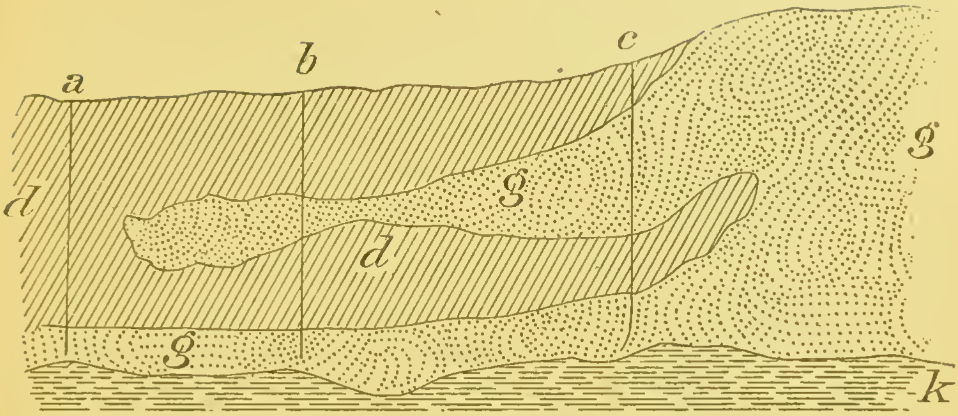
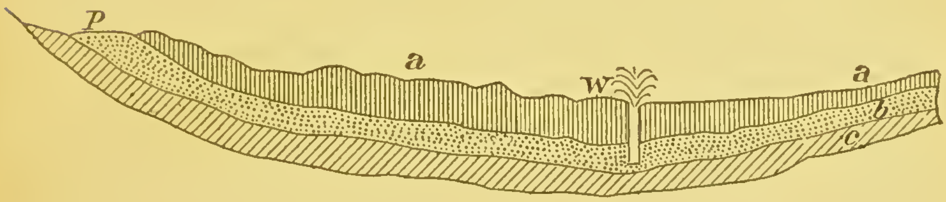
* *Mechanical News*, December 15, 1892.

† Wells of this class were first sunk, in Europe, at Lillers, in Artois, in 1126. In the Sahara and in China they have been known for many centuries.

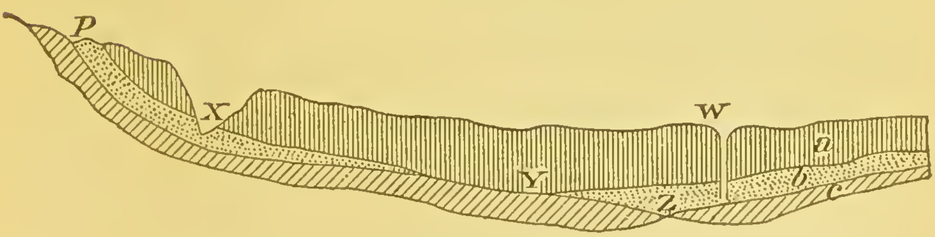


CONDITIONS OF WATER-BEARING STRATA IN RELATION TO OTHER FORMATIONS. (AFTER ROBERT HAY.)

a, well with one water-level; *b* and *c*, wells with two water-levels; *g*, water-bearing gravel; *k*, impervious shale.



CONDITION FAVORABLE FOR FLOWING WELL. (AFTER HAY.)



CONDITION UNFAVORABLE FOR FLOWING WELL. (AFTER HAY.)

vation of the gathering-grounds above the well, and to the freedom with which the water can flow down the porous stratum and escape through the outlets below.

It would be difficult to find an artesian field more deserving of study, or more interesting to the investigator, than the one underlying the southeastern corner of the United States, and which is tapped by the wells of Northern Florida, notably that of the Ponce de Leon at St. Augustine.

No one has better knowledge of that interesting well than Mr. W. Kennish, who was in charge during its construction. The following data concerning the boring, together with the analysis of the water, given later, are partly taken from private correspondence with Mr. Kennish and partly from his letters to the *Engineering News*:

"The pressure was found to be 17 pounds to the inch, and the flow 10 millions of gallons in 24 hours.

"A turbine wheel fed by this flow maintained 120 incandescent lights at 16-candle power, proving that the well was capable of supplying a force equal to 15 horse-power.

"Concerning the maintenance of the supply, we are possessed of information upon which to form a judgment. There are now in the town of St. Augustine and its immediate vicinity in the neighborhood of fifty artesian wells varying in diameter from 2 to 12 inches, and exactly the same force exists to-day as when the first well was driven about ten years since. Another ground for believing that the supply of water is so abundant that it will prove equal to any possible draught upon it by artesian wells lies in the unvarying pressure indicated by the very sensitive gauge of the electrical apparatus operated by the 12-inch well, surrounded as it is by wells on all sides being used in constantly varying quantities. Again, the increase in the diameter of the wells has been attended by more than a proportionate flow.

"While the dynamo was being operated by the 12-inch

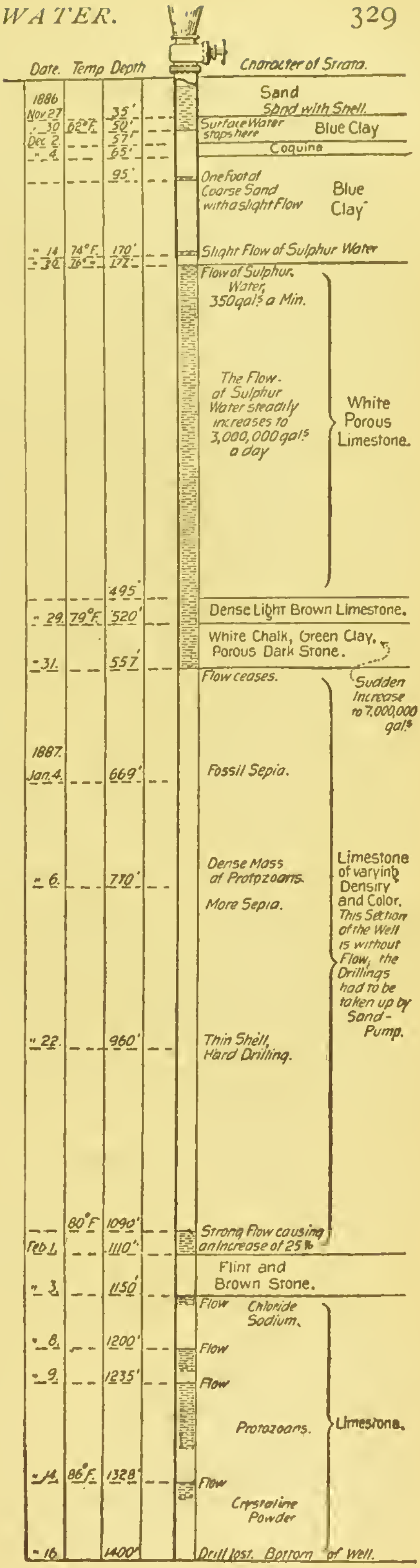
well a 6-inch well in its vicinity was turned on and off suddenly to test the steadiness of the force, but the closest observation did not detect the slightest trembling of the gauge.

"From these various sources of information we cannot escape from the conclusion that the water under pressure beneath St. Augustine and vicinity is practically boundless.

"The ratio of increase in temperature is very nearly 1° in every 50 feet. This increase was maintained until 86° was obtained at 1400 feet, where the well was stopped.

"Between 520 and 557 feet the rock changes from fossiliferous limestone to conglomerate of chalk, green clay, and a very porous dark fossil stone, largely composed of moulds of shells, the substance of which has been washed out.

"This stratum, of 37 feet in thickness, is doubtless cavernous, through which an enormous flow passes, possibly to find its partial escape in the great ocean spring, five miles seaward from Matanzas, and possibly, still further from the



PONCE DE LEON ARTESIAN WELL,
ST. AUGUSTNE, FLORIDA.

shore, and at greater depth, to swell the great ocean current —the Gulf Stream."

Such successive water-bearing strata as were encountered in the St. Augustine well are very frequently observed. Thus in a boring at Fort Worth, Tex., at a depth of 900 feet a stream of water was struck flowing 170 gallons per minute, with a pressure of 15 pounds per square inch. At a depth of 1035 feet another lower stream was reached of 200 gallons per minute and pressure of 21 pounds per square inch. This second stream having been also cased off, further boring developed a flow at 1127 feet in depth of 245 gallons per minute, with a pressure of 29 pounds per square inch.*

One interesting feature of the deep wells of Northern Florida and of the sea-springs off the coast is the very great distances the waters must flow in their subterranean passage from the uplands of the interior, for there is no land within a long distance of St. Augustine of sufficient elevation to produce the "head" observed at the wells.

Nearly akin to the Florida wells are those furnishing the public supply for Charleston, S. C., but the pressure and delivery from these latter are not so great.

There are three of these flowing wells at Charleston, all of about equal depth, and furnishing the following amounts of water daily:

$2\frac{1}{16}$-inch diameter............	200,000 gallons
$3\frac{1}{4}$ " "	300,000 "
$5\frac{1}{2}$ " "	1,250,000 "

They pass through the following strata:

Feet.		Feet.	
0 to 2	Mould	17 to 50	Blue clay
2 to 8	Yellow sand	50 to 61	Blue clay sands
8 to 12	Sandy clay	61 to 65	White sands
12 to 17	White sand	65 to 85	Sandy marl

* Senate Doc. 41, page 106, 52d Congress.

85 to 203	Argillaceous marl, with
203 to 293	nodules
293 to 390	Calcareous marl, with nodules
390 to 393	Arenaceous limestone
393 to 454	Calcareous marl
454 to 466	Arenaceous limestone
466 to 475	Calcareous marl
475 to 476	White limestone
476 to 489	Calcareous marl
489 to 540	Alumina magnesian marl
540 to 794	Marl
794 to 836	Micaceous marl, with iron pyrites
836 to 960	Marl with sandstone layers
960 to 998	Sand, considerable water
998 to 1000	Hard sandstone
1000 to 1215	Marl, sand, and clay
1215 to 1221	Sandstone, very hard
1221 to 1230	Marl, sand, and clay
1230 to 1310	Sandstone
1310 to 1345	Dark sand and clay
1345 to 1350	Broken shell and shell-rock
1350 to 1390	Blue clay, with hard layers
1390 to 1405	Green sand
1405 to 1533	Marl, some shell, and some iron pyrites
1533 to 1557	Hard sandstone
1557 to 1560	Sand, water-bearing
1560 to 1610	Argillaceous sand and sandstone
1610 to 1820	Blue clay and sand
1820 to 1845	Sand, with water
1845 to 1850	Sand-rock, hard
1850 to 1860	Loose white sand
1860 to 1862	Sandstone, hard
1862 to 1880	Loose sand, with water
1880 to 1900	Blue clay and sand
1900 to 1910	Sand
1910 to 1925	Argillaceous sandstone
1925 to 1970	Alternation of sand-beds 8 or 10 feet thick, and sandstone 2 to 5 feet thick between the beds
1970	Sandstone, not penetrated

The direct connection with the sea of the water-bearing layers which these wells tap is shown by the water in them rising and falling with the tide, and it is of special interest to note the fact that the daily fluctuations in the wells do not coincide in point of time with the tides at Charleston, a circumstance to be explained by the hypothesis of a very distant connection with the sea.*

A singular case, illustrating the danger that may possibly follow the tapping of water-bearing sand under pressure, is

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* Tidal influence in the case of ordinary domestic wells is not unusual. Thus in one locality in Hampshire, England, tides in the river affect a well 2240 feet distant. The well is 83 feet deep.

There was a famous temple of Melcarth at Gades, containing a mysterious spring which rose and fell inversely with the tide. (Bosworth Smith, "Carthage and the Carthaginians.")

mentioned in "Abstracts of Papers," Institution of Civil Engineers:*

"The town of Schneidenmuehl, in which the well referred to is situated, lies in the province of Posen, near the West Prussian boundary. In the autumn of 1892 the sinking of the well was commenced, and in May of the next year had reached a depth of 238 feet. From 49 to 52 feet of the upper layers were comparatively firm; then a layer of sandy silt was struck, having a thickness of 180 feet. A current of water was used during the boring operations as long as the upward pressure of the ground-water permitted. The tubes had a diameter of 4.72 inches to a depth of 82 feet, when they were reduced to 3.15 inches.

"On reaching a depth of 210 feet a strong current of muddy water issued from the tube. Sinking was continued, when at a depth of 236 feet the flow from the tube ceased; but a strong jet of water, amounting to 220 gallons per minute and containing 5 to 6 per cent of solid matters in suspension, issued through the ground at the side of the tube. The cause of the hydrostatic pressure which ejected the water with such force is sought for in the geological formation underlying the town of Schneidenmuehl. This town lies in the valley of the River Kuedow, an affluent of the Netze, and is partially surrounded by hills composed of drift sand, which offer little obstacle to the percolation of any rain-water falling upon them. Upon this sand, however, lies an impervious deposit composed of the more or less clayey sediment left by the river, and this deposit appears to have resisted the pressure of the water until it was pierced during the sinking of the well.

"An endeavor was made to stop the flow of water by drawing the tubes, but this proved unsuccessful, because all

* See also *Engineering News*, December 20, 1894.

solid matter which fell into the well from its sides was at once ejected with the water. Owing to the quantity of sand thrown out considerable subsidences of the surface took place, and the adjoining buildings were seriously damaged. Bags of sand and clay, stones, etc., were thrown into the well; but these were all swallowed up without staying the flow of water An attempt was then made to dredge out a well or shaft round the tube, but after eight days' hard work a depth of only 2 feet was reached, owing to the quantity of sand driven up from below. It was next decided to drive down several tubes to the depth from which the water came, and this was done; but several of the tubes sank and were lost, so that finally only one tube remained, the minimum diameter of which was 5.9 inches. On the 15th of June the ground sank suddenly to the extent of 4.26 feet, carrying with it part of the adjoining houses. After this the flow of water became less, and none reached the surface except through the tube. On the 21st of June tubes of gradually diminishing diameter were fixed upon the main tube, when it was found that the water rose to a height of 65.6 feet above the street-level. By means of taps at different levels the water was gradually cut off, and on the 22d of June it had altogether ceased to flow, and the danger to the town appeared to have been averted.

"On the 20th of September, however, the plug which closed the tube was removed, and the water again began to flow, sometimes containing as much as 20 per cent fine sand. The water forced its way upwards outside the tube, and finally the tube and the whole superstructure of the well sank. The method devised to close the well was to heap as rapidly as possible sufficient earth or sand upon the spot, so that the weight of the layer would counterbalance the upward thrust of the water. An area 69 feet in diameter was cleared, and the six tubes were carefully filled with fine

sand. The earth and sand which had previously been brought to the spot were thrown in at the rate of 1.962 cubic yards per minute until a conical mound was formed 6.56 feet high and 69 feet in diameter at its base. This method proved successful, and the issue of water from the bore-hole has now ceased."

Flowing wells at times occur which are not due to hydrostatic pressure, but to the lifting of local water by gas-expansion. Such a case is reported by Professor Hay as occurring in Southeastern Kansas.*

The same author also refers to "rock-pressure" as a cause of flowing wells of great depth. Such wells tap sections of rock which are, together with the contained water, under enormous compressive strain, and the partial release of pressure in one direction causes the water to rise in the tube.

A phenomenon occasionally met with in deep, non-flowing wells is that of "breathing." Mr. J. T. Willard, of Kansas, has reported a very interesting instance of that kind in which close observation was kept of the entrance or exit of air, and the corresponding barometric readings. With a low barometer the well air took an outward direction, and the reverse condition followed increased atmospheric pressure. Mr. R. T. Smith, of Winona, Kan., "utilized such an air-current to blow a whistle which could be heard all over the town, warning the inhabitants of a possible storm." Of course the volume of air moving in such cases is far greater than what would be equal to the cubic contents of the well-tube, and it comes from a storage in porous or cavernous strata.

Attention is called by various writers—notably by Messrs. Todd and Swezey—to the liability of these "breathing wells"

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* Senate Doc. 41, 52d Congress, page 38.

to freeze, owing to the sudden inflow of cold winter air from the outside. "The pumps not infrequently froze to the depth of 70 or 80 feet below the surface, and in one case ice had been found in a pump-cylinder 100 feet down, which was about 10 feet above the water."

Other things being equal, the ability of a well to furnish an abundant supply of water will depend upon the water-absorbing qualities of the rock in which the well is bored. The following values are given by Hill:*

CAPACITY OF ROCKS TO ABSORB WATER.

(Expressed in parts by weight of water absorbed by 100 parts of rock).

Sandstone	4 to 29
Chalk	24.10
Coal shale	2.85
Basalt	0.83
Granite (fine-grained)	0.12
Granite (hornblendic)	0.06

The author found the following values for the rocks of the State of New York:†

Diorite, Palisades	0.22
Granite, Peekskill	0.81
Granite, St. Lawrence	0.23
Gneiss, N. Y. City	0.19
Mica schist, N. Y. City	0.39
Hornblende schist, Antwerp	0.05
Red slate, Granville	0.00
Serpentine, Jefferson County	0.35
Talc, St. Lawrence County	0.43
Dolomite, St. Lawrence County	0.29

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*Senate Doc. 41, 52d Congress.

† Each specimen was weighed, soaked in water for forty-eight hours, rapidly wiped with a damp cloth, and again weighed.

Potsdam sandstone, Potsdam	1.90
Chazy limestone, Chazy	0.13
Bird's-eye limestone, Watertown	0.07
Trenton limestone, Trenton Falls	0.04
Hudson River shale, Cohoes	0.97
Oneida conglomerate, Utica	0.09
Medina sandstone, Medina	2.49
Green shale, Rochester	0.27
Clinton limestone, Rochester	0.23
Niagara shale, Rochester	1.13
Encrinal limestone, Lockport	0.11
Niagara limestone	0.63
Lower Pentamerous limestone, Schoharie	0.48
Oriskany sandstone, Oriskany Falls	1.44
Schoharie grit, Schoharie	0.32
Onondaga limestone, Jamesville	0.15
Blue flagstone, Kingston	0.39
Portage sandstone, Portageville	1.80
Conglomerate, Panama	3.73
Catskill sandstone, Catskill Mountains	0.90
Conglomerate, Catskill Mountains	0.55
Red shale, Catskill Mountains	0.72

Contrary to the belief of many people, deep-seated water is not inexhaustible. If the porous layers containing it be extensive, an immediately available supply of large volume, which is the accumulation perhaps of ages, may be counted upon; but should the daily drain be larger than the natural reinforcement, the delivery must surely shrink in quantity, and finally cease.

The serious effect of extending and heavily pumping the deep chalk wells supplying a portion of London is thus pointed out in the *British Medical Journal* for February 28, 1891:

"For every two gallons of water collected within the Lee valley London is withdrawing three from its reservoir in that chalk basin, and this quite apart from the amount every day required by the resident population of that area. The result

of such a process can only be a steady, if gradual, exhaustion of water from the chalk, and a progressive lowering of its plane of saturation; and, unfortunately, facts abundantly confirm this calculation, and prove that such a lowering of the deep-water level is proceeding, not merely in the valleys of the Colne and Lee, but in the main valley of the Thames itself as well; and this, moreover, to a degree which has already begun to excite the alarm of both agriculturists and manufacturers.

"Watercress-growing—one of the most important industries of Hertfordshire, and one which few Londoners would willingly abolish—is being seriously damaged, and is threatened with destruction at no very distant date. Springs which were perennial and abundant thirty years ago have now run dry; the level of the water in deep wells has fallen more than 20 feet within less than as many years. Mills are being abandoned for lack of water-power, and rivers which once flowed regularly past ancient mansions, built to command a view of their bank-full streams, are now lost in swallow-holes, or flow only scantily, or for a few weeks in occasional years. In 1821 the water in a well in the east of London stood at Trinity high-water mark—22 feet above the present ordnance datum; in 1851 its average height was 43 feet below; and in 1881 it was 105 feet below ordnance datum, a lowering of 127 feet in sixty years, and indicating a fall in the plane of saturation in the chalk of more than 200 feet in the century. This depletion is not explicable on any theory of a diminished rainfall; for in this district the average of the last twenty years (during which the fall has taken place at an increasing rate) is nearly two inches above the average rainfall for the previous thirty years. The cause is to be found wholly and solely in the fact that water has been, and is being, increasingly drawn from the chalk basin in excess of its supply. Under these circumstances is it strange that the

population of the large area so immediately affected should be alarmed, or that they should believe that they have the strongest grounds for opposing any schemes by which the rate of depletion must be enormously increased, to their own immediate loss, and to the ultimate devastation of their county?"

Deep water must not be expected in every locality. There is a widespread notion that every deep boring is sure to strike water in goodly quantity, if carried to sufficient depth, irrespective of any surface conditions whatever. The writer has been called to pass judgment upon the advisability of trying for an artesian supply for a settlement on the top of a mountain some three thousand feet high, and that, too, a mountain of erosion, with horizontal strata. Shallow borings, of only thirty to forty feet in depth, had furnished a limited quantity of water in the same general locality, and hence the proposition to increase the supply by the means above stated. The water obtained from the shallow wells was, of course, derived from the very local rainfall of the mountain-top, and was no indication whatever of a further deep supply, although the parties interested were of the opinion that water could be induced to run up hill, owing to some occult "artesian" conditions.

Water from deep sources has, commonly, characteristics of its own, distinguishing it from the ground-water of the neighborhood. One of the most easily recognized of these is high temperature. Albertus Magnus was the first to hold that low-lying waters are warmed by the native internal heat of the globe.*

An excellent illustration of the gradual increase in tem-

* Aristotle believed the high temperature of such water to be due to solar heat which penetrated the crust of the earth and accumulated in the interior as at the focus of a lens.

perature with depth of boring has already been given in data concerning the Ponce de Leon well.

Another peculiarity of deep water is the small quantity of dissolved oxygen it usually contains. This is by no means due to the pressure to which it may be subjected, for increase of pressure favors the solution of gases, but is rather owing to the abundant opportunity for removal of oxygen by contact with such substances as organic matter, and compounds of iron and manganese, presented during the long underground journey of the water from its point of collection.

The water of the Grenelle well at Paris, which flows from a depth of 548 metres (about 1780 feet), contains no oxygen whatever.*

In point of composition the waters of deep wells are almost always highly mineralized, as would be expected in consideration of the items of long time, long distance of flow, high pressure, and elevated temperature.† Sometimes the

* Richardson finds that, as water at normal temperature and pressure absorbs .0245 of its volume of air, at a depth of 1380 feet water would absorb its own volume of air (measured at atmospheric pressure). At a depth of 40,000 feet (the soundings for at least one spot in the Pacific Ocean) the air contained would be 29 times (measured under normal pressure) the volume of the absorbing water. (*Chem. News*, LXVII. 99.)

† The following analysis of water from "Old Faithful" Geyser may be taken as typical of such waters from the Yellowstone Park (Gooch and Whitfield, Bul. 47, U. S. Geol. Sur.):

NH_4Cl	trace	
$LiCl$	34	per million.
$NaCl$	639.3	" "
KCl	47.8	" "
$CsCl$	trace	
$RbCl$	trace	
Na_2SO_4	27	" "
KBr	5.1	" "
$Na_2B_4O_7$	21.3	" "
$NaAsO_2$	2.7	" "
Na_2CO_3	208.8	" "
Na_2SiO_3	27.9	" "
$MgCO_3$	2.1	" "

materials contained render the water unfit for use, even for boiler purposes, but more commonly the supply is such as to be considered a great boon to the fortunate possessor. Mr. Kennish furnishes the following analysis of the water from the Ponce de Leon well already spoken of. The water on issuing from the well smells strong of sulphuretted hydrogen (a quality also observed in the water of the Matanzas sea-spring), but all odor leaves it after standing a short time.

Suspended matter	1.6	per	million
Silica	28.0	"	"
Alumina	1.2	"	"
Sodium chloride	1957.7	"	"
Potassium chloride	47.5	"	"
Magnesium chloride	353.4	"	"
Calcium sulphate	470.9	"	"
Strontium sulphate	18.6	"	"
Magnesium sulphate	none		
Calcium bicarbonate	149.9	"	"
Magnesium bicarbonate	162.1	"	"
	3190.9	"	"

A somewhat curious instance of the change that may come in the composition of a deep-well water from attempts to increase the flow by deeper boring was brought under the author's observation a few years ago. At a depth of 800 feet a valuable "saline" mineral water was obtained. With a view to increase the flow the owners sank the well to 1406 feet, when the water suddenly changed to one of "alkaline

$CaCO_3$	3.8	per	million.
$FeCO_3$	trace		
$MnCO_3$	trace		
Al_2O_3	1.7	"	"
SiO_2	369.1	"	"
H_2S	0.2	"	"
	1390.8	"	"

carbonate" character, heavily charged with marsh-gas and sulphuretted hydrogen.

Some years ago a small sample of brown water was sent to this laboratory by the gas company of Mobile, Ala. It came from an artesian well 600 feet deep, bored near the Gulf coast. A very simple and partial examination was made of it to determine its fitness for boiler use. It was decidedly alkaline from the presence of sodium carbonate, contained considerable salt, and in color was of a dark coffee-brown. It is to be regretted that circumstances did not favor a complete analysis of so interesting and unusual an artesian water. However, the gap has been filled by Professor Reuben Haines, who recently reported a "remarkable artesian-well water" from Southern Alabama.* The description of the water, and the depth of the well (685 feet), combined with the location, lead to the conviction that the water was practically the same as the one examined by the writer some years ago.

The analysis and comments are best given in Professor Haines' own words:

"Color (observed in tube two feet long)—very dark coffee-brown.

"Odor (heated to nearly 100° C.)—unpleasant, odor of damp rotten wood.

"Taste (warm)—disagreeable, stale, brackish alkaline with organic flavor.

"Transparency—almost clear, a small amount of whitish sediment.

Free ammonia........................	6.900	per million
Albuminoid ammonia	0.740	" "
Oxygen consumed (Kubel).............	10.892	" "

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* *J. Fk. Inst.*, January, 1894.

Nitrogen in nitrates	0 40	per	million.
Chlorine	998.0	"	"
Total solid residue (dried at 120° C.)	2060.0	"	"

" The mineral ingredients existed in the following combinations:

Potassium sulphate	2.2	per	million
Potassium chloride	44.0	"	"
Sodium chloride	1611.9	"	"
Sodium carbonate	293.3	"	"
Calcium carbonate	26.8	"	"
Magnesium carbonate	13.4	"	"
Silica, iron oxide, and alumina	8.5	"	"
	2000.1	"	"

" The more remarkable features of this artesian-well water which are here to be noted are the very high color, approximating that of water from pools in bogs and swamps, and the enormous amounts of ammonia and of organic matter. Deep-well and artesian waters are usually colorless and particularly free from organic matter, on account of the vast amount of filtration to which they are generally subjected. It does not seem probable that so excessive an amount of ammonia as occurs in the Alabama well can be referred to decomposition of the vegetable substance alone, but that a portion of it, at least, must be caused by decomposition of the organic remains of fish and other marine animals, which have been, perhaps, partially preserved from decay through the antiseptic properties of peat. A quantity of bones and shells mingled with sand is stated to have been thrown up by this well.

" The excessive amount of sodium chloride in this well-water may be attributed to the probable existence of saliferous beds somewhere in the vicinity. From the results of

analysis it is manifest that the water has no direct connection with the sea, for its mineral composition is totally unlike that of sea-water. The pressure of the water at the mouth of the well is of itself sufficient evidence that the water has an altogether different origin."

Water of high color, and of general swampy character, is also to be found in the deep wells in the vicinity of New Orleans. Only one explanation is apparent for all these cases, and that is that the water coming from its distant gathering-ground is constrained, for a portion of its underground course, to pass through deep-lying deposits rich in organic remains.

As to what kind of rocks yield hard water and what kind furnish soft, we have but to consider the chemical and physical structure of the rock in question, and then, from the solubility data, a very fair judgment can be arrived at. Professor Carter has summed up this question very aptly.* He says:

"Water that passes through calcareous or magnesium rocks of great thickness will probably be hard, while water that passes through rocks composed of silica, alumina, iron, potash, or soda will probably be soft. The great deposits of limestone, marble, gypsum, and other calcareous rocks, as well as the magnesian rocks, such as dolomite, chlorite, and talcose schists, would then yield hard water. The granites, gneisses, and many sandstones and slates would furnish soft water. This, in the main, is true, although there are some exceptions which local conditions modify. Some sandstones will yield soft water, while other sandstones furnish hard water; it depends mainly upon the cement which binds the grains together. If the cementing material be carbonate of lime or sulphate of lime, the water will probably be hard,

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* *J. Fk. Inst.*, September, 1893.

especially if the well be of great depth and the water be long in contact with the rocks. If, on the other hand, the cementing material be feldspar, such as orthoclase or albite (not labradorite), or even gelatinous silica, the water will probably be soft.

"In England many determinations of the hardness of spring and artesian waters from different geological formations have been made; so that it can be safely predicted what kind of water an artesian well will yield when it is drilled in the Devonian, in the Silurian limestone, in the new red sandstone, or in the chalk.

DEEP ARTESIAN-WELL WATER (ENGLAND).

	Hardness.	
Water from Devonian sandstone	17°	Hard waters.
Water from magnesian limestone	43°	
Water from new red sandstone	17°	
Water from chalk	27°	

Water from granite and gneiss, soft.
Water from Silurian sandstones, slate, and shales, soft.
Water from millstone grit, soft.

"Water which flows through calcareous channels is hard, while that which flows through silicious rocks is soft."

As has been shown, deep water may at times be too highly mineralized, or even too "peaty," for potable use, but such impurity is not all that may be present on occasion.*

Even a deep well, especially if not a true flowing artesian, is not always exempt from local infiltrations of contaminating character. This is especially seen in the deep borings within the limits of the city of New York. The character and

* Sworn statements have been made to the effect that numerous small fish were found in water issuing from deep artesian wells in Aberdeen, S. D., 1891, six hundred miles from any known surface source of such fish. (Senate Doc. 41, 52d Congress, part 2, page 86.)

vertical position of the rock strata underlying the metropolis are such as to permit surface drainage to reach to very considerable depths. The writer condemned a deep-well water from Erie, Pa., upon the following analysis:

Free ammonia	2.025
Albuminoid ammonia	none
Chlorine	69
Nitrogen as nitrates	.025
Nitrogen as nitrites	none
"Required oxygen"	.85
Total solids	487
Phosphates	strong traces

Further information showed the well to have been bored within city limits, through a friable rock, and "within 75 feet of the nearest privy-vault."

Adverse report was also made upon another well, which had been very carefully bored through rock (shale) for 200 feet. Within 50 feet of the well was a large privy-vault. Sixty-five pounds of salt, dissolved in three barrels of water, were thrown into the vault, and the water of the well was watched for increased chlorine, with the following results:

Before "salting"	58·	parts chlorine per million
After 15 hours' pumping	64.25	" " " "
" 36 " "	64.37	" " " "

Other, but hardly necessary, instances could be given of contamination from adjacent elevator-shafts, gas-works, and the like.

The following interesting point was lately brought out by Mr. Fanning during discussion of a paper before the American Water-works Association. Mr. Fanning said:

"While recently making an examination of the sources

of water-supply for a city of New Jersey, located near a larger city, I gathered the data of the wells in the vicinity and over the southwestern part of the State with a view of learning the amount and direction of dip of the successive strata from the surface down, and of estimating the probable water-supply from the water-bearing sand strata available for a city water-supply. In that city the question of a well-supply had been earnestly discussed and was favorably considered. After plotting, in a diagram, the information showing the inclination and direction of the strata, the evidence seemed clear that the outcrop of the strata and the water-shed which would supply the water to wells in that city were in the neighboring city. It seemed to me unwise and unsafe for them to depend for their own water-supply upon the water that falls upon the surface in and about the neighboring city.

"This case illustrates the frequent necessity of tracing an underground water-supply to its surface source and water-shed, that there may be assurance that it is unobjectionable and clean, for if the source be unclean the filtration through the sand stratum will not protect it indefinitely."

Finally, a word concerning the probability of finding bacteria in deep wells. Waters from such sources are not to be rated as "uniformly sterile." Leaving out of consideration such instances as the New York City wells, which permit the direct entrance of surface drainage, there are yet many deep waters showing abundance of bacterial life; but, fortunately, the chances of encountering therein germs of objectionable character are reduced to a minimum. Prof. Sedgwick has lately reported his findings upon this question:

"From our results we are forced to the conclusion that ground-waters, even the waters of deep wells, may not be

by any means as free from bacteria as has been hitherto supposed.

"It is plain that water absolutely free from bacteria is not ordinarily obtained from even deep wells, and that many deep wells contain as numerous bacteria as are found in many surface-waters."

The bacteria present in these waters, are, however, "remarkable not only for slow growth, but, also, for the absence of liquefying colonies, and, in many cases, for the abundance of chromogenic varieties. These facts are especially important, as indicating the total absence of contamination by ordinary surface-water, and, as far as they go, they strengthen the confidence with which well-protected ground-waters may be regarded as sources of public water-supplies." *

* Sedgwick, Mass. Bd. of Health, 1894.

CHAPTER X.

CHEMICAL EXAMINATION OF WATER.

A GREAT deal of popular misconception exists upon the subject of the analysis of potable water, and it is commonly supposed that such an examination may be looked upon from practically the same point of view as the analysis of an iron ore. That this belief is founded on fallacy may, however, be readily shown. When an iron ore is submitted for analysis, the chemist determines and reports upon the percentages of iron, phosphorus, sulphur, etc., found therein; and at that point his duties usually cease, inasmuch as the ironmaster is ordinarily capable of interpreting the analysis for himself. Even should the analyst be called upon for an opinion as to the quality of the ore, the well-known properties of the several constituents make such a task an easy one, and, assuming the sample to have been fairly selected, the opinion may be written without any inquiry as to the nature of the local surroundings whence the ore was taken.

A water-analysis, on the other hand, is really not an analysis at all, properly so called, but is a series of experiments undertaken with a view to assist the judgment in determining the potability of the supply. The methods of conducting these experiments are largely influenced by the individual preferences of the analyst, and are far from being uniform or always capable of comparison, thus often introducing elements of confusion where two or more chemists are employed to analyze the same water. Some of the substances reported—"albuminoid ammonia," for instance—do not exist

ready formed in the water at all, and are but the imperfect experimental measures of the objectionable organic constituents, which our present lack of knowledge prevents our estimating directly.

Thus the numerical results of a water-analysis are not only unintelligible to the general public, but are not always capable of interpretation by a chemist, unless he be acquainted with the surroundings of the spot whence the sample was drawn, and be posted as to the analytical methods employed.

It is very common for water to be sent for analysis, with the request that an opinion be returned as to its suitability for potable uses, while at the same time all information as to its source is not only unfurnished, but is intentionally withheld, with a view of rendering the desired report unprejudiced in character.

Such action is not only a reflection upon the moral quality of the chemist, but it seriously hampers him in his efforts to formulate an opinion from the analytical results.

For instance, a large quantity of common salt is a cause for suspicion when found in drinking-water, not because of any poisonous property attaching to the salt itself, but because it is usually difficult to explain its presence in quantity except upon the supposition of the infiltration of sewage; yet an amount of salt sufficient to condemn the water from a shallow well in the Hudson valley could be passed as unobjectionable if found in a deep-well water from near Syracuse, N. Y.

We thus see how important it is for the chemist to be fully acquainted with the history of the water he is to examine in order that he may compare his results in "chlorine" with the "normal chlorine" of the section whence the sample is taken.

A knowledge of the history of the water is no less important in order to interpret the remaining items of a water-

analysis. Some time since a water was sent from Florida to this laboratory for examination, and was found to contain 1.18 parts "free ammonia" per million. Much "free ammonia" commonly points to contamination from animal sources, and had it not been known that the water in question was derived from the melting of artificial ice made by the ammonia process the enormous quantity of ammonia found would have condemned it beyond a peradventure. As it was, the water was pronounced pure, the other items of the analysis having been found unobjectionable.

Analytical results which would condemn a surface-water are unobjectionable for water from an artesian well, for the reason that in the latter case high figures in "free ammonia," "chlorine," or "nitrates" are capable of an explanation other than that of sewage-infiltration. Even though such water should have, at a previous period, come in contact with objectionable organic waste material, yet the intervening length of time and great distance of underground flow would have furnished abundant opportunity for thorough oxidation and purification.

"Deep" samples taken from the same lake, at the same spot and depth, will greatly vary in analytical results if the temperature of the water at the several dates of sampling should be markedly different, owing to the disturbing influence of vertical currents.

Again, suppose it is desired to determine whether or not the water of a large stream is so contaminated with upstream sewage as to be unfit for a town supply. An analysis of the water taken from the site of the proposed intake would very probably be valueless, because the enormous dilution to which the admitted sewage would have been subjected would remove from the analytical results everything of an absolute character. Examinations of any real value in such cases should always be of a comparative nature.

Samples should be taken above and below the point of contamination and again at the proposed intake. If the difference between the first and second samples, which is a measure of the pollution, be maintained, or nearly so, at the point of intake, then the water should be condemned, no matter how completely the analytical results fall within the limits of the so-called standards of organic purity.

Thus it is that a chemist must be in full possession of all the facts concerning the water which he is asked to examine, in order that his opinion as to its purity may be based upon the entire breadth of his past experience, for in no branch of chemical work is experience and good judgment better exercised than in the interpretation of a water-analysis.

As Nichols has well said, "It is a great mistake to suppose that the proper way to consult a chemist is to send a sample of water in a sealed vessel with no hint as to its source. On the contrary, the chemist should know as much as possible as to the history and source of the water, and, if possible, should take the samples himself."

However faithfully the various chemical tests may be applied to the question of the fitness or unfitness of a certain water for dietetic purposes, there is nothing upon which greater stress should be laid than a thorough personal knowledge of the surroundings of the source of supply.

It has been held as a golden maxim by one of our best authorities on water-analysis "never to pass judgment upon a water the history of which is not thoroughly known," and the nearer this maxim can be lived up to the fewer will be the mistakes in the reports issued.

In the taking of samples for so important a matter as a town supply the chemist should unquestionably personally superintend their collection; but for individual outlying waters printed instructions have to be frequently depended upon. Those issued from this laboratory are as follows:

DIRECTIONS FOR TAKING A WATER-SAMPLE.

Large glass-stoppered bottles are best for sampling, but as they are seldom at hand, a two-gallon *new* demijohn should be employed, fitted with a *new* soft cork. Be careful to notice that no packing-straw or other foreign substance yet remains in the demijohn, and thoroughly rinse it with the water to be sampled. Do not attempt to scour the interior of the neck by rubbing with either fingers or cloth. After thorough rinsing fill the vessel to overflowing so as to displace the air, and then completely empty it.

If the water is to be taken from a tap, let enough run to waste to empty the local lateral before sampling; if from a pump, pump enough to empty all the pump connections; if from a stream or lake, take the sample some distance from the shore, and plunge the sampling-vessel a foot and a half below the surface during filling so as to avoid surface-scum.

In every case fill the demijohn nearly full, leaving but a small space to allow for possible expansion, and cork securely. Under no circumstances place sealing-wax upon the cork, but tie a piece of cloth firmly over the neck to hold the cork in place. The ends of the string may be afterwards sealed if necessary.

Bear in mind, throughout, that water-analysis deals with material present in very minute quantity, and that the least carelessness in collecting the sample must vitiate the results. Give the date of taking the sample, as full a description as possible of the soil through which the water flows, together with the immediate sources of possible contamination.*

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* Fear of cholera has lately caused waters to pour in floods into some of the analytical laboratories of Europe, and it is more interesting than reassuring to observe the methods followed in dealing with this accumulated work.

In the laboratory of one public analyst the writer saw a large collection of water-samples, as yet unopened, from various localities.

These samples, some of which were weeks old, had been collected in a

Having secured the sample, begin the analysis at once, for the reason that water is liable to rapid changes in character during laboratory storage. For instance, the following analyses are of the same sample of water from the laboratory tap, drawn November 10, and allowed to stand in the sampling-bottle at ordinary room temperature:

	Nov. 10	Nov. 12	Nov. 13	Nov. 14	Nov. 15	Dec. 15
Free ammonia	.037	.042	.042	.050	.075	.060
Albuminoid ammonia	.220	.178	.191	.175	.155	.205
Chlorine	4.5	......	......	......	......	......
N in nitrites	trace	trace	trace	trace	trace	none
N in nitrates	.50	.525	.55	.60	.60	.60
Required oxygen	4.35	4.6	4.2	4.4	4.1	4.6
Total solids	140	......	......	......	......	......
Loss on ignition	11	......	......	......	......	......

This water shows gradual oxidation of the nitrogen contents to nitrates, but on the whole is fairly stable. As showing, on the other hand, how rapid and how ununiform the storage changes may at times be, the following analyses by Liversidge are given.* (See table, top of next page.)

These are, of course, exaggerated cases containing high ammonias, but they serve to point out the necessity of avoiding delay between the collection of the sample and the be-

variety of vessels, principally claret- and whiskey-bottles, and the corks employed were often old ones.

When one considers the excessive care required for water-sampling, the thought that the above lot were doubtless taken by inexperienced hands, with the aid of vessels certainly old and probably unclean, does not increase one's faith in the value of the analytical results.

Much to my surprise, I also saw in one laboratory the old writing-paper packing for connecting the retort with the condenser, a method of union long since discarded for something more reliable. It is so easy a matter to ruin a water-analysis by indifferent attention to the proper setting up of the apparatus for the "albuminoid ammonia" process that modern practice discards, as inefficient, several recommendations made by Wanklyn, the originator of the method, and among them the paper packing mentioned.

* *Chem. News*, LXXI. 249.

	Horse-pond.		Fish-pond.		Peaty Water.	
	Free Ammonia.	Albuminoid Ammonia.	Free Ammonia.	Albuminoid Ammonia.	Free Ammonia.	Albuminoid Ammonia.
December 11..	10.00	7.00	0.12	0.90	0.72	0.19
" 12...	2.00	2.00	0.11	0.92	1.12	0.04
" 13...	8.00	4.00	0.16	1.04	1.12	0.13
" 15...	7.00	4.00	0.16	1.03	1.08	0.12
" 16...	6.00	2.00	0.38	0.69	0.03	0.04
" 19...	5.00	2.00	0 52	0.56	0.02	0.03
" 20...	4.00	1.00	0.70	0.38	0.01	0.01
" 21...	2.00	0.50	0.90	0.30	....	....
January 8.....	0.50	0 25	1.38	0.06	....	....
" 10....	0.07	0.07	1.50	0.04	....	....

ginning of the analysis. At the most, very few days should intervene.

Another example, chiefly interesting as showing the successive steps in the oxidation of organic nitrogen, is here given.* Eighty samples of water, including all classes of surface-water, were examined at various intervals after standing, and gave the following results:

"The organic matter in suspension decays in about seven days, as is shown by the increase in 'free ammonia.' In about fourteen days this 'free ammonia' has disappeared, and 'nitrite' has taken its place, reaching a maximum in about twenty-one days. Later the 'nitrite' also disappears, and in twenty-eight days, or more, all the nitrogen has been converted into the form of 'nitrate.' When the suspended matter is removed by filtration through paper, or by precipitation with alumina, no change occurs, unless free ammonia were present at the outset."

Hitherto no small confusion existed, on account of the many ways in which the results of water-analyses were stated, but this difficulty, it is to be hoped, will be greatly done away with by the report of the committee of the

* Report of the Massachusetts Board of Health, 1890, 865.

American Association for the Advancement of Science, appointed to examine into this and other water questions.

It was with a view to advance the cause of "uniformity" that the "water committee," of which the author was a member, was appointed by the chemical section of the American Association for the Advancement of Science, at its Buffalo meeting in 1886. The preliminary report of the committee may be found in the *Journal of Analytical Chemistry*, vol. iii., page 398.

The committee recommended that all results be given in *parts per million in weight.* This method has the advantage that a litre, or fraction thereof, of water, having been operated upon, and the substances found having been determined in milligrammes, no long arithmetical calculations will be required.

Of course the assumption is made that a litre of water weighs a kilogramme—a true enough statement for potable waters, but one capable of introducing error where mineral waters are dealt with, whose specific gravities are appreciably above unity. In such a case the water is actually weighed, or else the weight is estimated from the known specific gravity and volume.

Water should not be filtered before analysis. If sediment be present, it should be equally diffused by thorough shaking before measuring.

The reason for this is that a water-analysis should represent the water as the consumer uses it, and not in a condition improved by filtration.

Water-analysis cannot be properly conducted in a general laboratory, because many of the tests would be ruined by the fumes common to such a locality. A separate room, reserved exclusively for water-work, is the best arrangement.

The author finds it convenient to have the woodwork painted white and to have a broad titration shelf fixed across the window, with a black curtain capable of being pulled down to the level of the titration-dish. Excellent conditions are thus given for noting slight changes in colors, as required in the determination of chlorine.

The appearance of a water is most conveniently noted in a glass tube two inches in diameter, two feet long, and closed at the ends by pieces of quarter-inch plate-glass. These tubes, as commonly constructed, have both end-plates cemented on, and the water is introduced through a small hole in the side of the cylinder. This is a poor arrangement, as it interferes with necessary cleaning. A better plan is to have but one end-plate fixed, as the other can be easily held in place by the hand, without any leakage occurring, while the tube is held horizontally for purposes of observation.

No suitable standards covering degrees of turbidity have been established, and the observer must be content to describe what he sees in words. Of course, should a special case demand it, the suspended material causing the turbidity could be filtered from a known volume of the water by means of a weighed Gooch crucible with asbestos felting, and its weight determined both before and after ignition. This would give some idea of the amount and quality of the turbidity.

Odor and Taste.—It is customary to report such odor and taste as a water may possess, although in the great majority of cases very little information is derived from such examination, because of the frequency of negative results. A good water may be possessed of a slight marshy odor, while one of extremely dangerous character may be limpid,

tasteless, and odorless. The test, such as it is, is best applied before and after heating the water to the boiling-point, and after thorough shaking in each case.

Temperature.—A cool water should, if possible, be supplied for public use, but studies of temperature are exceedingly rare, for the sufficient reason that considerations of far greater weight determine the selection of a source of supply.* Should many temperature readings in deep water, as in a lake, be decided upon, no better device could be chosen for the work than the "thermophone," invented by Warren and Whipple. The following is clipped from a description issued by the present makers, E. S. Ritchie & Sons, Brookline, Mass.:

"The thermophone is an electrical thermometer of the resistance type. It is based upon the principle that the resistance of an electrical conductor changes with its temperature, and that the rate of change is different for different metals.

"The operation of taking a reading is as follows: Having connected the leading wires to the proper binding-posts of the indicator-box, the current is turned on and the telephone held to the ear. A buzzing sound in the telephone is found to increase or diminish according as the pointer is made to approach or recede from a certain section of the dial. By moving it back and forth a position may be found where the telephone is silent. When at this point, the hand indicates the temperature of the distant coil. Instruments of ordinary atmospheric range, i.e., from 15° to 115° F., may easily be read to 0.1° even by an inexperienced observer. With

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* The extreme variation of temperature for Croton water, as delivered by the street hydrants in New York City, for the year 1894 was:

On February 24	34° F.
On August 4	76° F.

a smaller range, or with an instrument having a larger dial, a greater precision may be obtained.

"It is more sensitive than a mercurial or other expansion thermometer, because the rate of change of resistance per degree is greater than the rate of expansion of liquids or solids, and, moreover, slight changes in resistance may be more easily and accurately measured than slight changes in length or volume.

"It sets quicker than most mercurial thermometers. In obtaining the temperature of water of various depths one minute has been found to be sufficient time to allow for setting.

"It is independent of pressure." *

The reaction of potable water is not often determined quantitatively. Should it be deemed necessary to measure it, the method in use at Montsouris is as convenient as any other. The water is distinctly acidified with $\frac{N}{15}$ sulphuric acid, and then titrated with $\frac{N}{25}$ ammonia hydrate, using cochineal as an indicator.†

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* The deepest sounding found on the Challenger expedition was in lat. 11° 24′ N., long. 143° 16′ E. The depth was 4475 fathoms.

Temperature of bottom-water	33.9° F.
" of surface- "	80° F.

Most of the thermometers employed were crushed by the great pressure of five tons per square inch.

† It must be remembered that in attempting to take the reaction with litmus paper of so dilute a solution as potable water one must be prepared to occasionally encounter what is known as "amphoteric action," that is, a turning of blue paper red and red paper blue within limits that are at times quite wide. Such waters contain CO_2 both free and combined, and the peculiar action referred to is "simply the result of competition for the base between the free carbonic acid and the red litmus, which is itself a weak acid having blue salts. When the red paper is placed in a solution containing carbonates and free carbonic acid, it seizes a portion of the base until equilibrium is established. If the blue paper be placed in the solution, the free carbonic acid robs it of a part of the base, and liberates red litmus until the same condition of equilibrium is reached. (Seyler, *Chem. News*, LXX. 141.)

Color.—Prof. A. R. Leeds has proposed the most convenient method for stating the color of a water.* Observations are made by the use of 50-c.c. "Nessler" jars, and unity of color is that caused by "Nesslerizing" 1 c.c. of the standard ammonium chloride solution, diluted to 50 c.c. with ammonia-free water, in exactly the same manner as in the determination of "free ammonia." (Page 389.)

Turbid waters should be filtered before reading the color.

As supplementary to what has been already said concerning the relation of the observed depth of color in a water to the amounts of iron and manganese contained therein, a number of determinations of iron in peat-forming materials, made by the Boston Water Board, are given below. The board finds that whereas iron enters largely as a cause of color in water from the stagnant layer of a deep pond, the color of a purely surface-water is mainly due to solution of organic material.†

AMOUNT OF IRON IN DIFFERENT MATERIALS (DRIED AT 100° C.).

Leaflets of common brake	.006%
Maple-leaves	.042%
Elm-leaves	.052%
Meadow grass, growing from tussock	.006%
Meadow moss, fresh	.038%
Meadow moss, one year or more old, and some grass	.190%
Recent peat, from tussock	.034%
Brown vegetable mould, from decayed stump	.210%
Black peaty muck, from 2 to 3 feet	.920%

* For cases of special investigation the Hazen "platinum" standard gives most excellent results, although somewhat more difficult to apply. (*Am. Chem. J.* XIV. 300.)

† An excellent paper by Mrs. Ellen H. Richards on "The Coloring Matter of Natural Waters" was lately read before the chemical section of the A. A. A. S. at its Springfield meeting, and is published in *J. Am. Chem. Soc.*, January, 1896.

Having accomplished the foregoing preliminary observations, the examination proper comes now in order; but before going further a word should be said upon the vexed question of "standards for interpretation of analytical results."

A hard-and-fast "standard" is simply an impossibility, as indicated at the opening of this chapter. Results which would be considered satisfactory for one locality might be entirely inadmissible in another. Local standards are the proper ones by which to be guided, and it is to be regretted that local "normals" are not more frequently found on record.

Mr. Reuben Haines offered the following figures representing the averages of thirty-four different determinations of uncontaminated waters, and recommended them as standards for pure waters in the neighborhood of Philadelphia:

	Parts per Million.
Free ammonia	0.031
Albuminoid ammonia	0.044
Chlorine	11.9
Nitrogen as nitrates	5.075
Total solids	125.7

For Massachusetts the information is more full, as is instanced by the fine chart of "normal chlorine" prepared by the State Board of Health.

Following the description of each analytical process to be given hereafter there will be placed a paragraph headed "Standards," but the expression must not be permitted to mislead. The author's intention is simply to place before the reader the opinions of various authorities, and he absolutely disclaims any desire to set boundaries to the free use of the analyst's good judgment. The term "standards" is doubtless a poor selection, but, with the above explanation, it will serve in place of a more lengthy expression.

TOTAL SOLIDS.

Source.—Material dissolved or suspended in water is naturally derived from the strata through which the water passes, or the surface over which it flows. Thus are obtained waters of all degrees of hardness (see "Hardness") and of great variety of color and turbidity.

Determination.—Thoroughly shake the vessel containing the sample and then measure out 100 c.c. of the unfiltered water by means of a pipette into a weighed platinum dish.

Evaporate to dryness on the water-bath, being careful to place a filter-paper between the dish and the water in the bath in order to prevent any deposit of impurities on the under side of the dish. (A better plan is to make use of a porcelain water-bath filled with distilled water.) When dry, place the dish and contents in an air-bath and maintain the temperature at 105° C. for half an hour.* Cool in a desiccator and weigh. Replace in the air-bath and repeat the weighing at intervals of half an hour until a constant weight be obtained. The final weight, less the known weight of the dish, will give the amount of total solids. This weight multiplied by ten will give the weight of solids per litre of water, which, expressed in milligrammes, will represent parts per million.

It was formerly the custom to ignite this residue, moisten with carbonic acid water, and again ignite and weigh. The loss in weight was reported as organic matter.

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* Dr. Albert Levy, of the Montsouris laboratory, Paris, dries this residue at 180° C. for twelve hours before weighing. He gives the following illustration of how differently various waters act when dried at 125° C. and 180° C.:

	125°.	180°.
Vanne	231	231
Ourcq	483	445
Marne	328	289
Drain St. Maur	300	290

Concerning such treatment Tidy remarks: "It presupposes three things: (*a*) that no organic matter is lost and none is gained during the evaporation of the water; (*b*) that all the organic matter is burned off by the ignition of a residue; (*c*) that nothing *but* organic matter is lost by ignition; but in all these points the process fails."

It is unnecessary to further detail the fallacies of this exploded method, but it is important to note that while no quantitative results are to be expected from the ignition in question, yet considerable insight may often be obtained as to the character of the water by observing the intensity of the charring and the presence or absence of fumes.

Dr. Angus Smith goes so far as to say: "It is remarkable what a clear insight is given into the quality of water by simply burning the residue. We can, by the eye and smell, detect humus or peaty acids, nitrogenous organic substances (smell of burnt feathers), and nitrates, and estimate their amount to a very useful point of accuracy."

Dr. Smart says: "The blackening during the process is of more interest than the mere loss of weight. No matter how few parts are lost, if the lining of the capsule blackens all over and the carbon is afterward dissipated with difficulty, the water is to be viewed as suspicious. What are called 'peaty' waters here constitute the exception." *

Dr. Smart conducts the ignition "at a gentle heat, gradually attained," a rule to be followed in all cases. Angus Smith pointed out that "in waters containing nitrates and nitrites no organic matter would be apparent on burning unless more should be present than these salts could oxidize" —a fact always to be borne in mind.

Analysts commonly weigh the dish and contents after heating to redness, and report the "loss on ignition."

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* Report Nat. Board of Health, 1880.

NOTE.—So much difficulty is often experienced in weighing the "total residue" when the water contains hygroscopic salts, owing to the rapid absorption of moisture, that the author has of late substituted a large glass "weighing-bottle" for the platinum dish in this determination. The bottle is constructed with a small stopcock in place of a handle on its cover, in order to permit introduction of air, and consequent easy removal of the cover after the weighing is completed. The vessel is used in the same manner as the platinum dish, but, being covered upon withdrawal from the air-bath, the weighing may be done at leisure. Another 100 c.c. of the water is quickly evaporated in platinum, and ignited, in order to observe the blackening of the residue, if there be any.

Standards.—As to the quantity of total solids that unpolluted water should contain, it would be well to note the following:

Rivers Pollution Commission of Great Britain gives as averages out of 589 samples analyzed for total solids:

Rain	29.5
Upland surface	96.7
Deep well	432.8
Spring	282.0

Dr. Smart (Nat. Board of Health, 1880):

Safe limit	300
To be condemned	1000

A. R. Leeds (Water Depart. Wilmington, 1883):

Standard for American rivers	150 to 200

Wanklyn regards as permissible 575

NOTE.—It is indeed rare for water to be considered *too* pure, but in a recent paper on the Loch Katrine water, which supplies the city of Glasgow, it was proposed to effect the silicizing of the water by bringing it in contact with red sandstone, thereby neutralizing its action on lead pipe, and checking any action it may have in producing infantile deformity, which many people, rightly or wrongly, ascribe to the use of this water.*

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* *J. Soc. Chem. Ind.* v. 649.

HARDNESS.

Before entering into the question of quantitative estimation, let it be premised here that "hardness" may be classified under two heads, viz., "Permanent" and "Temporary." The former is occasioned by the presence of calcium sulphate, and other soluble salts of calcium and magnesium, not carbonates, held in solution by the solvent action of the water itself; such a water cannot be materially softened by boiling under ordinary pressure.

"Temporary" hardness is caused by carbonates of calcium and magnesium held in solution by carbonic acid present in the water. Boiling such a water expels the carbonic acid, whereupon the salts separate from solution.*

Many samples of water possess both "permanent" and "temporary" hardness, and the analyst is at times called upon to report each separately; but more commonly the total hardness covers all that is required.

Ordinary hard soap is somewhat complex in structure, but for practical purposes we may consider it to consist of sodium stearate, $NaC_{18}H_{35}O_2$. This salt, coming in contact with the calcium carbonate or sulphate contained in a hard water, is immediately decomposed, with formation of insoluble calcium stearate according to the following equations:

$$CaCO_3 + 2NaC_{18}H_{35}O_2 = Ca(C_{18}H_{35}O_2)_2 + Na_2CO_3$$

or

$$CaSO_4 + 2NaC_{18}H_{35}O_2 = Ca(C_{18}H_{35}O_2)_2 + Na_2SO_4.$$

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* With some it is considered that the calcium is present as a soluble bicarbonate which breaks up upon boiling into carbonic acid gas and insoluble normal carbonate; but, as A. H. Allen says, it is not necessary to assume the existence of calcium bicarbonate (which compound has never been isolated) in order to account for the solubility of calcium carbonate. One water which he examined evolved very small quantities of carbon dioxide on boiling, and yet the precipitated calcium carbonate was large in amount. He considers it "probable that calcium carbonate is capable of existing in a soluble colloid condition,

Of course none of the soap can be depended upon for detergent purposes until all the calcium salts present have been thus provided for; hence the enormous waste resulting from the use of some waters may readily be imagined.*

In undertaking the estimation of hardness advantage is taken of the reaction above stated. A solution of soap of known strength is prepared, and is then poured into a given quantity of the water to be examined, until a permanent lather is formed, whereupon, from the known quantity of soap used, the amount of "hardening" salts present may be calculated.

This soap test, commonly known as Clark's, is not accurate, and is in some respects unscientific; but it is not without value, especially in a locality such as Troy, N. Y., where the enormous laundries use soap by the ton.

Soap Solution.—From a new cake of Castile (Syria) soap scrape ten grammes of shavings. Dissolve them in one litre of dilute alcohol ($\frac{1}{3}$ water). If not clear, filter, and keep tightly stoppered.†

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changing, on boiling the liquid, to the ordinary insoluble modification." (*J. Soc. Chem. Ind.* VII. 801.)

* "While no exact rule can be given for estimating the increased expense to a community caused by the use of hard water, in general it may be said (*Eng. News*, January 31, 1885) that each grain of carbonate of lime per gallon of water causes an increased expenditure of 2 ounces of soap per 100 gallons of water. The Southampton water contains about 18 grains of lime and magnesian salts per gallon. With such hard water it is probable that the increased expense for soap in a household of five persons would amount to at least $5 to $10 yearly; hence the inhabitants could afford to pay a higher water-rate by the amount of this difference for a soft-water supply." (*Engineering News*, April 16, 1892.)

† The above solution the author has always found satisfactory. Courtonne recommends the following, which he claims does not alter with lapse of time:

Olive-oil	28 grammes
Sodium hydrate solution of 36° B.	10 c.c.
Alcohol of 90% to 95%	10 c.c.

Saponify on the water-bath. Agitate with 800 to 900 c.c. of alcohol of 60% to dissolve the soap. Filter into a litre flask, cool, and fill to the mark with 60% alcohol.

Standardizing the Soap Solution.—Carefully weigh out one gramme of pure $CaCO_3$. Dissolve in a little HCl. Neutralize with a *slight* excess of NH_4OH and dilute to one litre. Each cubic centimetre of this solution will contain an amount of calcium salt equivalent to one milligramme of $CaCO_3$.

Place 10 c.c. of this solution in an eight-ounce glass-stoppered bottle, make the volume up to 100 c.c. with pure water, and run in the prepared soap solution from a burette, little by little (shaking after each addition), until a lather be formed which persists for five minutes. Even when the amount of soap solution required is approximately known, never add more than half a cubic centimetre at once, and never fail to shake after such addition.*

Note the amount of soap solution used. Now repeat the experiment, using 100 c.c. of pure water only (no calcium salt solution), and again note the amount of soap solution required. This second reading will give the amount of soap solution (no inconsiderable quantity) used up by the 100 c.c. pure water, and by subtracting the same from the reading obtained in the first instance knowledge will be reached of the quantity of soap required for the calcium salt alone. Estimate now the value of 1 c.c. soap solution in terms of calcium carbonate and record the result on the bottle. Perhaps an example would be in keeping:

8.2 c.c. soap solution are required for 10 c.c. $CaCO_3$ solution + 90 c.c. water.

0.6 c.c. soap solution are required for 100 c.c. water.

Hence

7.6 c.c. soap solution are required for 10 m.g. $CaCO_3$ only.

Hence

1 c.c. soap solution corresponds to 1.316 m.g. $CaCO_3$.

* See *Chem. News*, August, 1886.

Always place the date of standardizing on the bottle, and re-standardize frequently, as the soap solution is not premanent.

Determination.—Place 100 c.c. of the water in the eight-ounce bottle, run in the standard soap solution in the manner already stated, read off the amount required, multiply by the known value for 1 c.c. soap solution, multiply this again by ten, and there will be obtained the hardness expressed in so many parts of $CaCO_3$ per million of water.

It was formerly customary to report hardness in "degrees" rather than parts per million, but the difficulty of deciding which of the several systems of degrees was referred to provoked so much confusion that a change was made to the present simpler mode of expression.*

Should a report of both temporary and permanent hardness be called for, the soap test must be made both before and after boiling.

If the hardness due to salts of magnesia be required separately, shake the water up with a little solid ammonium oxalate, filter off the precipitated calcium oxalate on a dry filter, and determine the hardness in the filtrate.

When a water is so hard as to require a greater amount of soap solution for the 100 c.c. of the water than suffices to saponify 23 m.g. $CaCO_3$, better results are obtained by diluting with an equal bulk (or more, if necessary) of pure water, inasmuch as too heavy a precipitate of the calcium stearate appears to interfere with the proper lathering. Of course the influence of the additional quantity of water must be allowed for.

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* In England the Clark scale is in use. Each degree corresponds to one grain of $CaCO_3$ per imperial gallon of water, i.e., one part in seventy thousand. Below 6 degrees is considered soft.

For constant results the hardness of a water should be taken at a temperature of 15° C.*

Standards. — The average hardness of good waters as given by the British Rivers Pollution Commission stands:

Rain	3
Upland surface	54
Deep well	250
Spring	185

Wanklyn allows 575

Leeds's standard for American rivers, 50 for soft, 150 for hard

J. Chem. Soc. LXIV. II. 347.

CHLORINE.

Water is rarely found free from chlorine, yet, notwithstanding its almost constant presence, there is hardly a factor in the sum total of water-analysis towards which attention is more quickly turned, or regarding which there is closer scrutiny.

Excepting in unimportant instances, chlorine is always present in the form of common salt, washed from the air or soil, or added as one of the constituents of sewage. Salt itself is, of course, unobjectionable in the quantity usually present, but being, as it is, so largely used in our food, there is always warrant for suspecting sewage contamination where the figures for chlorine run high.

True it is that those figures are at times misleading, but they, like other data in water-analysis, must be considered with judgment, and due weight be accorded the character of local surroundings.

If the district whence the water comes be naturally rich in salt, as, for instance, the deep-seated waters of Central New York, such fact must be borne in mind when formulating an opinion as to qualtity. Comparison should be made with a local water, of the same general character, known to be pure; and for that purpose State maps, such as that given herewith for the State of Massachusetts, would be most valuable, and their construction would be well worth the expenditure of public money.

The influence of the sea upon the "normal chlorine" of Massachusetts is made very apparent by the chart. Such influence is naturally very marked in an insular country like England.

"The amount of chlorides in the rain is nearly always greater in the winter months than in the summer months. An abnormal amount of chlorides can generally be traced

to storms from the southwest of England bringing salt spray from the Bristol Channel, about thirty-five miles distant. Crystals of common salt have been found after such storms on the windows of the college facing west. On one occasion, in September, 1867, Professor Church found chlorine equivalent to 6.71 grains of common salt per gallon (69.7 parts per million of chlorine) in storm-water." *

Prof. Kinch reports the average amount of chlorine in the rain-water collected at Cirencester, England, during a period of twelve years to be 3.36 parts per million.

This variation in the chlorine-contents of rain-water may also occur inland, although not to the same degree. Thus the mixed monthly rain and melted snow at Troy, N. Y., contains the varying amounts of chlorine already given on page 206.

While not strictly city rain-waters, the Troy samples were doubtless somewhat affected by the neighborhood of the city. Ground-water is more directly influenced than rain-water by the presence of human habitation. Thus the Massachusetts Board of Health (1890 [1], 680) finds that twenty persons per square mile will add, on the average, 0.1 part per million of chlorine to the water flowing from such district.

The determination of chlorine in water is extremely simple. It depends upon the fact that, if to a solution of a chloride, which has been colored yellow by addition of a little potassic chromate, a solution of silver nitrate be added, white silver chloride will be produced until the last trace of chlorine be disposed of, whereupon red silver chromate will begin to appear.

The reagents required are:

Standard Silver Solution.—Prepared by dissolving 4.8022 grammes of crystallized silver nitrate in one litre of water.

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* *Chem. News*, December 10, 1886.

Each cubic centimetre of such a solution is of a strength sufficient to precipitate one milligramme of chlorine. A sample of this reagent a year old gave exactly the same results as when freshly prepared. In common with all other reagents for water-analysis, it should be kept in bottles having caps covering the stoppers, such as are used for volatile liquids.

Potassium Chromate, Indicator.—Dissolve 2 grammes of the pure salt in 100 c.c. of distilled water.

Saturated Sodium Carbonate Solution. — Dissolve 50 grammes of the pure salt in 300 c.c. of distilled water.

Determination.—One hundred c.c. of the water to be examined are placed in a porcelain dish; 1 c.c. of the potassic chromate solution is added, which will give a distinct yellow color, and then the standard silver solution is run in from a burette, until the red tint of the silver chromate just appears. From the known amount of silver solution used the amount of chlorine present is obtained, and this, multiplied by ten, will give the chlorine in milligrammes per litre or parts per million.

For the sake of accuracy it is better, during the titration, to have a second dish of water, also colored with potassic chromate, in order that the formation of the red tint in the dish operated upon may, by contrast, be more readily detected.

For determination of chlorine in any single sample of potable water likely to be encountered the above process is abundantly accurate, but should the work be of a comparative character, such as the watching of possible changes in the same water on different dates, or noting the variation in composition due to the flow of a river, it would be better to operate upon a larger quantity of water.

For such purpose it is best to place one litre of the water in a large porcelain casserole, add 0.1 c.c. of the sodium

carbonate solution to avoid the possible loss of chlorine during evaporation, evaporate to 100 c.c., and titrate as above.

Many waters give such deep color upon concentration, however, as to interfere with proper titration; under such circumstances it would be best to shake the water with recently precipitated aluminum hydrate and filter before measuring out the litre for evaporation. The coloring matter is thus removed.

The material loss of chlorine that may occur should the evaporation be conducted without the addition of sodium carbonate is illustrated by the following experiment:

To each of two litres of water 3.35 milligrammes of chlorine were added, in the form of common salt. To one of them was likewise added 0.1 c.c. sodium carbonate solution. Upon evaporating each to 100 c.c. and titrating they gave the following results:

Water with carbonate added.........	3.35 m.g.	of	Cl
Water with no carbonate added....	3.25	"	"

The porcelain of the dish does not interfere with this determination, but it is very important to carefully scrub and wash down its sides after evaporation. It is also important to always evaporate to the same volume (i.e., 100 c.c.), for, as Hazen has shown, "the volume of liquid in which the chlorine is determined has an effect on the amount of silver solution used in the titration." It makes no difference at what rate the silver solution is added during titration.

With waters high in chlorine it is often very difficult to decide just when the red color begins to appear, for the reason that it is hard to compare the clear yellow liquid of the comparison-dish with one which has become turbid from precipitation of silver chloride.

Following a suggestion of my assistant, Mr. V. H. Gridley, it is now my practice to roughly determine the chlorine

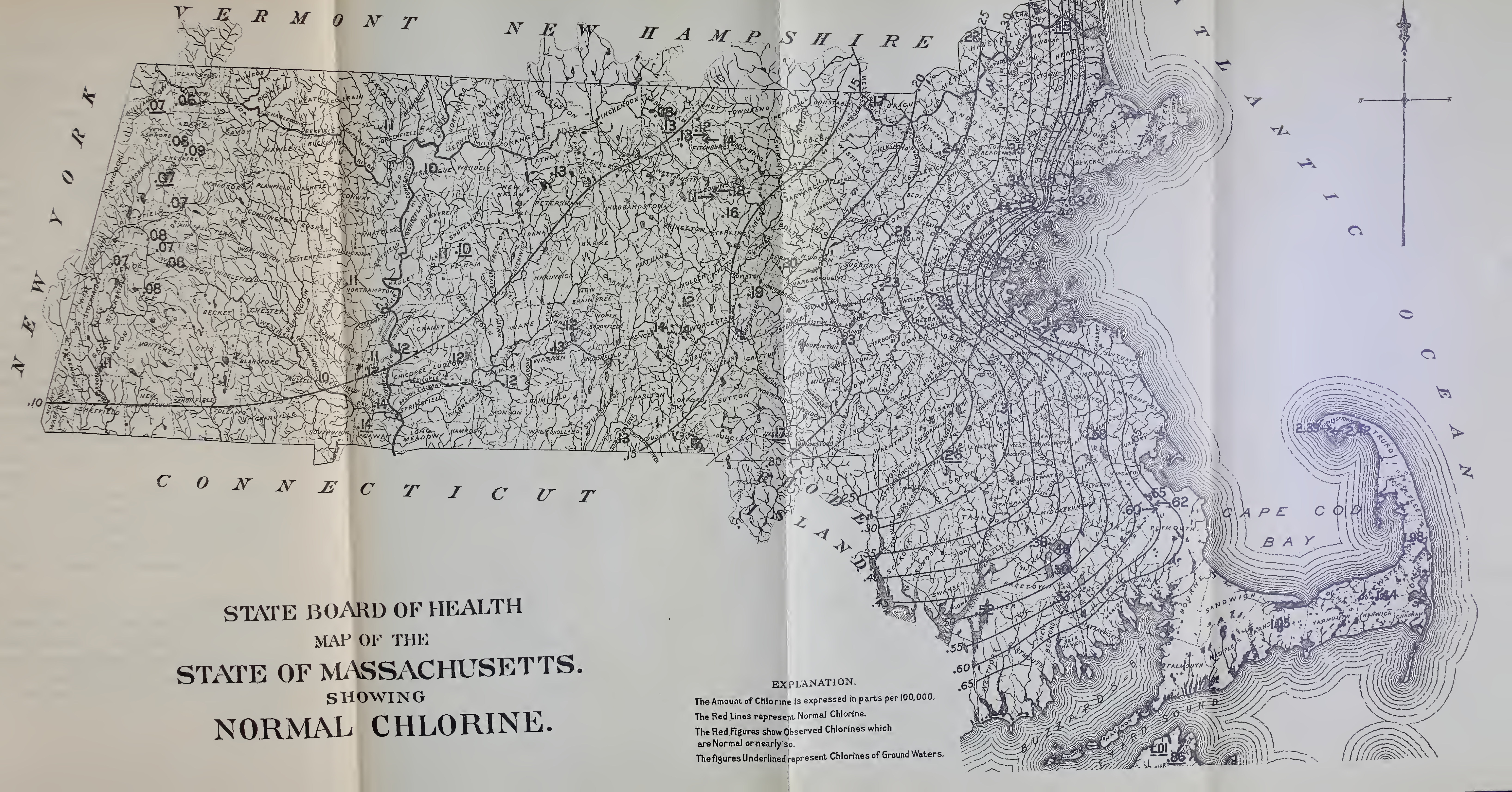
present, and then to make a second determination, using for comparison 100 c.c. of distilled water to which has been added not only the chromate indicator, but also an appropriate amount of standard sodium chloride solution, and an amount of silver nitrate solution just short of that necessary to satisfy the chlorine present. Of course if the chlorine ran so high as to render concentration unnecessary, then 100 c.c. of the water itself, with the indicator and the partial dose of silver nitrate, would be the proper contents of the comparison-dish.

By these means the eye is greatly aided in noting the slightest appearance of red tint, for in respect of turbidity both dishes are alike. If analysis of sewage be contemplated, it would be better to abandon volumetric methods entirely, and weigh the silver chloride precipitate directly.

Standards. — The Rivers Pollution Commission reports the average amount of chlorine in 589 samples of unpolluted water as follows:

Rain	8.22
Upland surface	11.3
Deep well	51.1
Spring	24.9

Wanklyn considers 140 as possibly suspicious.
Frankland considers the permissible limit as 50.
Leeds's standard for American rivers, 3 to 10.
Ordinary sewage, about 110 to 160.
Human urine (average of 24 samples), 5872.



STATE BOARD OF HEALTH
MAP OF THE
STATE OF MASSACHUSETTS.
SHOWING
NORMAL CHLORINE.

EXPLANATION.

The Amount of Chlorine is expressed in parts per 100,000.
The Red Lines represent Normal Chlorine.
The Red Figures show Observed Chlorines which are Normal or nearly so.
The figures Underlined represent Chlorines of Ground Waters.

NITROGEN AS NITRITES.

Frankland writes: "When fresh sewage is added to water already containing nitrates, the latter are generally reduced to nitrites," and it may be there are none to disagree with him; but when he adds that "when nitrites occur in shallow wells or river-waters, it is highly probable that these waters have been very recently contaminated with sewage," thereupon Wanklyn declares that "nitrates and nitrites have been erroneously regarded as measuring the defilement of water." Finally, in the report of the National Board of Health for 1882 Mallet concludes: "With the facts of this investigation before me I am inclined to attach special and very great importance to the careful determination of the nitrites and nitrates in water to be used for drinking."

This statement of Prof. Mallet so entirely accords with the uniform experience of the writer as to force him to regard it as conclusive. It is based on most carefully conceived and executed experiments which "point strongly to the production of nitrites by oxidation of organic nitrogen, and their subsequent conversion into nitrates by further process of oxidation."

Whether, therefore, the presence of nitrites be considered due to reduction of pre-existing nitrates in presence of organic matter, or caused by direct oxidation of organic nitrogen, it becomes a necessity to estimate their quantity, for in either case the initial cause is probably contamination.

Of the several methods used of late for the determination of nitrites the second one suggested by Griess seems to be the most deserving of favor. It depends in principle upon the red coloration ("azobenzolnaphthylamine sulphonic acid") produced whenever "sulphanilic acid" and "naphthylamine hydrochloride" are added to an acidified solution of nitrite.

The test is exceedingly delicate and is capable of distinguishing one part of nitrogen as nitrous acid in one thousand million parts of water.

The reagents are prepared as follows:

Sulphanilic Acid.—Dissolve 1 gramme of the salt in 100 c.c. hot water. The solution keeps well.

Naphthylamine Hydrochloride.—Boil ½ gramme of the salt with 100 c.c. water for ten minutes, keeping volume constant. Place in glass-stoppered bottle and add a little pulverized carbon to decolorize the solution. It tends to grow slightly pink on standing, but not sufficiently so to interfere with its use. Filter from carbon when required for use.

Standard Solution of Sodium Nitrite.—Sodium nitrite may be bought, but its purity is always to be questioned, and moreover it is too deliquescent a salt to be weighed with ease and accuracy. It is better, therefore, to prepare the silver salt, which may be readily handled, and from it the solution required may be made.

To a cold solution of commercial sodium or potassium nitrite add a solution of silver nitrate as long as a precipitate appears. Decant the liquid and thoroughly wash the precipitate twice with cold water. Dissolve in boiling water. Concentrate and crystallize the silver nitrite from the hot solution. Dry in the dark at the ordinary temperature (using vacuum is better) and keep for use.

Weigh out .22 gramme of the dry silver nitrite. Dissolve in hot water. Decompose with slight excess of sodium chloride, cool if necessary, and dilute to one litre. Allow the precipitated silver chloride to settle, remove 5 c.c. of the clear solution, and dilute the same to one litre. This second dilution (which is the standard solution to be used) will contain an amount of nitrite per cubic centimetre equivalent to .0001 milligramme of nitrogen.*

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* The standard solution here advocated is much weaker than the one rec-

Determination.—In order to undertake the determination of nitrites place 100 c.c. of the water to be examined in a "Nessler" jar. Acidify with one* drop concentrated HCl. Add 1 c.c. of the sulphanilic acid solution, followed by 1 c.c. of the solution of hydrochloride of naphthylamine, mix,† cover with watch-glass, and set aside for thirty minutes. Prepare at the same time other "Nessler" jars containing known amounts of the standard solution of sodic nitrite and diluted to the 100 c.c. mark with *pure* distilled water (see page 387), adding the reagents as above. At the end of the time stated (thirty minutes) examine the depth of the pink color formed, and by comparing the unknown with the known an accurate determination of the amount of nitrogen present as nitrites may be made.

Standards.—In a report upon the presence of nitrites in eighteeen "natural waters, believed from actual use to be of good, wholesome character," and collected from every variety of source, Mallet's determinations show an average of .0135 part nitrogen as nitrites per million parts of water. The average, by the same investigator, for nineteen waters "which there seems to be fair ground for believing have actually caused disease" is .0403 part per million.

In this connection, however, it would be well to bear in mind Frankland's statement that "the presence of these salts in *spring* and *deep-well* water is absolutely without significance; for although they are in these cases generated by the deoxidation of nitrates, this deoxidation is brought

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ommended by the committee of the A. A. A. S , the latter being undoubtedly too strong for convenient use. The committee's solution contained .01 m.g. nitrogen as nitrite per cubic centimetre.

* Addition of too much acid might cause *nitrates* to react as well. (*Analyst*, XII. 51.)

† To accomplish this mixing it is best to use a stout glass rod ten inches long, at one end of which is fused a cross, composed of two pieces of glass rod ¾ inch in length. The mixer is used as a plunger.

about either by the action of reducing mineral substances, such as ferrous oxide, or by that of organic matter which has either been imbedded for ages, or, if dissolved in the water, has been subjected to exhaustive filtration." This is merely another instance of how careful the analyst should be to become familiar with the source of the water before undertaking to pass judgment upon its quality.

Nitrites should always be looked upon with suspicion if found in ground- or surface-waters.

The absence of nitrites, moreover, proves nothing. I have recently had a most foul cistern-water for analysis which showed but a trace of nitrites and no nitrates, and yet the water was contaminated with the entire house drainage, and produced most serious illness.

Leeds's standard for American rivers, 0.003.

NITROGEN AS NITRATES.

Taking Mallet's statement as final, that there is every reason for assuming that nitrates present in water may be but the further step in the oxidation of nitrogenous organic matter, it necessarily becomes important to obtain an estimate of this constituent, which, in Frankland's opinion, is a factor in the measurement of "previous sewage contamination."

The value of such determination may be further accentuated upon noting that Dr. Bartley, president of the American Society of Public Analysts, found, to his surprise, that well-water contaminated with drainage from cow-stables had, in several instances, shown little or no free nor albuminoid ammonia (Wanklyn's measures of contamination), although large amounts of nitrites and nitrates were detected.

Nitrates are more liable to indicate putrefaction of animal rather than of vegetable tissue, not only because of the greater quantity of nitrogen present in the former, but also on account of its more ready decomposition.

Stoddart claims that "natural waters can, at most, obtain but from $\frac{1}{10}$ to $\frac{2}{10}$ grain of nitrogen as nitrates per imperial gallon (1.43 to 2.86 per million) from sources other than animal matter; and practically the whole of the nitrogen of sewage may be oxidized into nitric acid without diminishing the risk involved in drinking it."

"The proposal to consider a water safe so soon as the nitrogen has assumed the oxidized condition, irrespective of the quantity that may be present, is entirely irrational."*

Rain-water washes a very considerable amount of nitric nitrogen from the atmosphere; thus an official report gives the following amounts of nitrogen as nitrates in sundry rain-waters, showing at the same time the tendency of neighboring towns to increase this item:

* *Analyst*, XVIII. 293

England, interior	.19
" cities	.22
Scotland, near the coast	.11
" interior	.08
" cities	.30
" Glasgow	.63
Montsouris, Paris, average of 18 years	.73

Nitrogen in the soil is increased by the fixing of atmospheric nitrogen through the agency of the roots of certain plants, such as peas, the process being aided by bacterial action.*

Such fixed nitrogen eventually enters the ground-water, and a knowledge of the local "normal" for nitric nitrogen is consequently of advantage when studying the domestic well-waters of a neighborhood.†

After having tried many ways for the determination of "nitrates" in potable water the writer has adopted a modification of the old "picric acid method," as giving, on the whole, the greatest satisfaction.

Phenol-sulphonic acid is made by the action of phenol on sulphuric acid:

$$C_6H_5OH + H_2SO_4 = C_6H_4(OH)SO_3H + H_2O.$$

This reagent, reacting with nitric acid, forms tri-nitro-phenol,

$$C_6H_4(OH)SO_3H + 3HNO_3 = C_6H_2(OH)(NO_2)_3 + H_2SO_4 + 2H_2O,$$

which forms yellow ammonium picrate when acted upon by ammonium hydrate: ‡

* An interesting experiment to show this was recently made in France. Peas were grown in a closed space, and the nitrogen lost by the confined air was found equal to what was gained by the ground and plants. No such fixation of nitrogen could be obtained if the soil were previously sterilized.

† Surface- and ground-waters of good quality are low in nitrates, for the reason that such material is quickly absorbed by growing vegetation.

‡ See *Analyst*, x. 200.

$$C_6H_2(OH)(NO_2)_3 + NH_4OH = C_6H_2ONH_4(NO_2)_3 + H_2O.$$

The intensity of this yellow color, produced in the water under examination, is compared with standard colors of known strength, and the quantity of nitrate present thus determined.

The interference of chlorides with this process, resulting in readings decidedly lower than the truth, is well known, but the method is so easy and convenient that it occurred to the writer to try the addition of sodium chloride to the comparison standards rather than abandon the process.

The "chlorine" in the water under examination having been previously determined, an appropriate volume of standardized sodium chloride solution is added to each evaporation of standard potassium nitrate solution. Thus the water to be examined, and the nitrate solutions with which it is compared, all contain the same quantity of chlorine. The results are very satisfactory.

The solutions required are:

Phenol-sulphonic Acid.

Sulphuric acid, pure and concentrated........	148 c.c.
Distilled water..................................	12 c.c.
Pure phenol......................................	24 grammes

Standard Potassium Nitrate Solution. — Dissolve .7221 gramme pure KNO_3 in 1 litre distilled water. Dilute 100 c.c. of this solution to 1 litre with distilled water. This weaker solution, which is the standard employed, contains .01 milligramme of nitrogen as nitrate in each cubic centimetre.

Standard Sodium Chloride Solution. — Dissolve 1.6497 grammes pure NaCl (made from metallic sodium) in 1 litre distilled water. Each cubic centimetre will contain 1 milligramme of chlorine.

Determination.—Evaporate 100 c.c. (or less, according to nitrate-contents) of the water to dryness on the water-bath, having previously added $\frac{1}{10}$ c.c. sodium carbonate solution (see page 372) to prevent loss from volatilization of nitric acid. Thoroughly moisten the residue with 2 c.c. of the sulphonic acid. Add an excess (about 15 c.c.) of ammonium hydrate. Make up to 100 c.c. in a "Nessler" jar, and compare the depth of color with those produced by operating upon different amounts of the standard nitrate solution, which have been evaporated and treated under precisely similar conditions.

To each selected volume of standard nitrate solution there should be added before evaporation $\frac{1}{10}$ c.c. sodium carbonate solution and an amount of standard sodium chloride solution sufficient to correspond with the amount of chlorine previously found to exist in the water.

These evaporations, both of the water and the comparison standards, are best made in deep evaporating-dishes of glass $3\frac{5}{8}$ inches in diameter, and easily holding 100 c.c.

After dryness is reached the dish, with its contents, should be at once removed from the water-bath.

It is of the greatest importance that the conditions governing the operations to which the water is subjected should be strictly followed in preparing the comparison solutions.

Standards. — Referring again to Mallet's report before quoted,* we find a very marked difference between the average amount of nitrates present in good, as compared with the quantity found in bad, waters.

In thirteen samples of water "known to be pure" the nitrogen present as nitrates averaged 0.42 (the extreme limits being none and 1.04), while in twenty samples of water believed to be objectionable the average figures ran

* Report National Board of Health, 1882.

as high as 7.239 (the extreme limits being none and 28.403). Such a difference justifies Mallet's statement that he regards the determination of nitrates as of great importance.

Elkin: dangerously polluted if in excess of....	6.00
Vienna Commission allows..................	1.04
Hanover " "	2.60
Brandes " "	7.00
Fischer (*Jour. für Prakt. Chem.*)...............	7.00
Leeds's standard for American rivers... 1.11 to	3.89

The Rivers Pollution Commission gives the following averages from 589 unpolluted waters for nitrogen as nitrites and nitrates *together*:

Rain..................................	0.03
Upland surface..........................	0.09
Deep well..............................	4.95
Spring................................	3.83

As illustrating how widely the nitrates may vary in deep wells of good character the following list is taken from the *Analyst*, xx. 84:

Depth of Well in Feet.		N as Nitrate.
200.	Stratford	0.00 per million
200.	Wimbleton....	0.43 " "
490.	Chatham..................	6.85 " "
900.	Southend..................	0.71 " "
600.	Witham	6.43 " "
160.	Mistley	0.71 " "
430.	Braintree..................	0.28 " "
305.	Colchester................	0.00 " "
400.	Norwich..................	11.43 " "

Fresh sewage is often found entirely free of either nitrites or nitrates simply because the organic nitrogen present has,

as yet, not had sufficient opportunity to become oxidized thereto.*

* The sewage of Troy, N. Y., contains (sample of December, 1895):

	Parts per Million.
Free ammonia	.875
Albuminoid ammonia	.675
Nitrogen as nitrates	none
Nitrogen as nitrites	trace
Chlorine	31
"Required oxygen"	89
Total residue	489
Loss on ignition	315

ORGANIC MATTER.

A revolution has been worked during recent years in the determination of organic matter in potable water. Methods have arisen and disappeared. Authors of the highest rank have combated each other in print, with a success in establishing their views that has not always been commensurate with their positiveness in stating them.

It was in an effort to throw a little unprejudiced light upon the several processes of rival writers that Mallet undertook the investigation from the report of which we here so often quote—an investigation that required a period of years for its accomplishment, and which marks an era in the history of water-analysis. As therein referred to there are three methods of estimating organic pollution worthy of special mention, viz.: (*a*) the combustion process of Frankland; (*b*) the albuminoid ammonia process of Wanklyn; (*c*) the ' Forschammer'' process as modified by subsequent investigators.

Concerning the first, which is a direct combustion of a water residue, after the manner of an ultimate organic analysis, we note the following in the *Analyst* for September, 1885: "It is subject to many causes of error, and is of so extremely delicate a nature as to be almost abandoned at the present time." In his report to the Philadelphia Water Board for 1884 Dr. Leeds, referring to this method, says: "The determinations were discontinued, because the amount of information which they afforded did not appear commensurate with the great labor which they involved."

This remark of Dr. Leeds is almost identical with statements made to the author by Albert-Levy and other French authorities.

Speaking of the method, Mallet says: "It cannot be taken up offhand and even tolerable results obtained at once.

From the hands of a person without proper laboratory training its results are utterly valueless. It is hence better adapted to regular use in a large public laboratory than to occasional use by a private individual in now and then examining a single water."

In short, Frankland's combustion method is difficult, liable to error in unpractised hands, and its results are not indispensable for forming a correct opinion of the sanitary value of a water.

A far more general method for obtaining information as to organic impurity is Wanklyn's

Albuminoid Ammonia Process.—By the employment of this method a knowledge of the amount of "free ammonia" present is also obtained.

We may outline the process as follows: The "free ammonia" is distilled from a measured quantity of the water, and its amount is determined by what is known as "Nessler's" method, which will be described later. A strongly alkaline solution of potassic permanganate is then added to another portion of the water and the distillation is repeated. Nitrogenous organic matters are thereby broken up and the resulting ammonia ("albuminoid"), which distils over with the steam, is determined by the "Nessler" method, in like manner as before. It must be noted that the so-called "albuminoid" ammonia does not exist ready formed in the water, but is a product of the decomposition of organic nitrogenous substances by the alkaline permanganate. The term is derived from the fact that "albumen" gives off ammonia, in like manner, when similarly treated.

The reagents necessary are:

"*Nessler's*" *Solution.*—Dissolve 16 grammes mercuric chloride ($HgCl_2$) in about half a litre of pure water. Dissolve 35 grammes potassic iodide (KI) in about 200 c.c. pure water. Pour the first solution into the second, until a faint

show of excess is indicated. Add 160 grammes solid potassium hydrate (KOH). Dilute to one litre, and finally add strong solution of mercuric chloride, little by little, until the red mercuric iodide just begins to be permanent. Do not filter from excess of mercuric iodide, but let the same settle to the bottom of the vessel. The finished reagent should have a pale straw color. It is improved by age.

"Nessler's" solution will give a distinct brownish-yellow coloration with the most minute traces of ammonia or ammonium salts. If the quantity of ammonia be at all considerable, a brown precipitate will appear. The reaction in case of either precipitate or coloration will be

$$2(2KI,HgI_2) + NH_3 + 3KOH = \overline{NHg_2IH_2O} + 7KI + 2H_2O.$$

Pure Water.—This must be prepared with great care, in a room free from the usual laboratory fumes. In short, as has been already said, the entire examination of potable water should be undertaken in a locality other than a general working-laboratory. Fit a two-gallon retort to a large Liebig condenser, fill with good spring-water, distil, collect distillate in 50-c.c. "Nessler" jars, and to each successive jarful so collected add 2 c.c. "Nessler" solution.* After waiting five minutes, should a brown tint be observed upon looking through the liquid (*longitudinally*) at a white porcelain tile or piece of white paper, the presence of ammonia is indicated.

Continue the distillation and the "Nesslerizing" of the successive 50-c.c. portions of the distillate until no coloration is obtained even after standing for five minutes. When ammonia ceases to be detected, the distilled water may be

* The "Nessler" jars here used are carefully prepared, so as to have a uniform distance ($8\frac{1}{2}$ inches) between the bottom of the jar and the 50-c.c. mark. No mixer or stirrer is ever employed, as the high gravity of the "Nessler" solution causes it to quickly sink into and mix with the comparatively light distillate.

collected for use. The distillation should not be pushed too far, both on account of danger to the retort and of possible production of ammonia from decomposition of the organic material remaining in the bottom. In this laboratory we have for some time made use of a two-gallon copper retort with tin worm, and find it most satisfactory for the preparation of ammonia-free water. There is no objection to its use, provided it be so carefully looked after as to prevent any approach to dryness.

Alkaline Potassic Permanganate.—Dissolve 200 grammes solid potassic hydrate (KOH) and 8 grammes crystallized potassic permanganate ($K_2Mn_2O_8$) in 1250 c.c. of pure water. Boil down to one litre and keep for use.

Sodic Carbonate Solution.—Dissolve 50 grammes of the pure salt in 300 c.c. pure water.

Standard Ammonia Solution.—Dissolve 1.5706 grammes of pure dry ammonium chloride in half a litre *pure* water. Dilute 5 c.c. of this solution to half a litre with *pure* water. This second solution will represent a strength of .01 m.g. of NH_3 per cubic centimetre, and is the standard solution used.

DETERMINATION OF FREE AMMONIA.

Fit a one-quart glass tubulated retort to a large Liebig condenser,* letting the neck of the retort pass well into the condensing-tube (3 or 4 c.m.) and making the connection with a piece of large-size soft-rubber tubing. This connection must be thoroughly tight. Place 200 c.c. *pure* water in the retort and add 10 c.c. of the sodic carbonate solution. Distil off two 50-c.c. jarfuls of water, and "Nesslerize" the second in order to be sure that no ammonia yet remains in the retort. Any ammonia that may have resulted from the imperfect cleaning of the apparatus, or that may have been present in the sodic carbonate solution, will usually all go over in the first 50 c.c. of distillate, but the same quantity (i.e., 100 c.c.) must be distilled off in all cases in order that when the actual analysis of the unknown water is started upon the condition as to volume may be always constant.

In fact, it may be conveniently stated here that *perfect uniformity of conditions* is a requisite for success in water-analysis.

To the contents of the retort is now added half a litre of the water to be examined.

Distil and catch the distillate in 50-c.c. "Nessler" jars. The rate of the distillation should be so managed as to allow about fifteen minutes for the filling of each 50-c.c. jar. Add 2 c.c. "Nessler" reagent to each jarful, and continue the operation with each successive portion of the distillate until no further reaction for ammonia is apparent after waiting five minutes. Usually four jarfuls will be sufficient to carry off all free ammonia.

From a small burette measure definite amounts of the *standard ammonia solution* into several clean "Nessler"

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* For a description of the retorts, condensers, etc., used in this laboratory see page 400.

jars. Dilute each to the 50-c.c. mark with pure water, add 2 c.c. "Nessler" solution, and after standing for five minutes compare as to depth of tint with the distillates already "Nesslerized." With a little practice it will be found easy, by varying the amounts of standard ammonia solution used, to produce colors corresponding to those existing in the distillates, and thereby a most accurate knowledge of the quantity of ammonia actually present may be obtained. Such ammonia existed ready formed in the water, either free or as an ammonium salt, and passed over unchanged with the steam; it is therefore technically known as "*free ammonia.*"

To make clear the calculation of results let us cite an example: Suppose the first jarful to have required 9 c.c. standard ammonia solution (diluted to 50 c.c.) to match its color when "Nesslerized," the second one 3 c.c., and the third 1 c.c. Then, since each cubic centimetre of the standard. ammonia solution corresponds to .01 m.g. NH_3, the whole amount of "free ammonia" present in the original half litre of water would be:

1°	.09
2°	.03
3°	.01
4°	.00
	1.3 m.g.

Multiplying this by two, to obtain the quantity for an entire litre, and remembering that 1 m.g. is the millionth part by weight of a litre of water, we find the total "free ammonia" present in the water to be 0.26 *part per million.*

ALBUMINOID AMMONIA.

Throw out the residue remaining after the distillation for *free ammonia*, rinse the retort thoroughly, and refit it to the condenser. Place in the retort 200 c.c. pure water and 50 c.c. of the *alkaline permanganate solution.* Distil off three 50-c.c. jarfuls, and "Nesslerize" the third one in order to insure freedom from ammonia. Add half a litre of the water under examination, and proceed with the distillation, and the "Nesslerizing" of the successive 50-c.c. portions of the distillate, as in the determination of *free ammonia.* The distillation is to be continued as long as is compatible with the safety of the retort, unless the ammonia should sooner cease to be evolved. The ammonia determined by this distillation will be *total* (i.e., "free" plus "albuminoid"); therefore from the Nessler reading of each jarful of distillate must be subtracted the reading for the corresponding jarful for "free ammonia," the difference will give the "albuminoid ammonia."

The calculation is entirely similar to that for *free ammonia*, as stated.

Interpretation of Results.—Concerning the interpretation of results, Wanklyn, the inventor of the method, is very dogmatic, and says: "The analytical characters, as brought out by the ammonia process, are very distinctive of good and bad waters, and are quite unmistakable. There is, indeed, hardly any branch of chemical analysis in which the operator is less exposed to the risk of failure." This statement is altogether too strong. Waters of great organic purity, or those of great pollution, are undoubtedly easy to classify, but with the great mass of cases which lie about the boundary-line between "good" and "bad" the greatest care is to be exercised in the reading of results and the

passing of judgment. One rule, already mentioned, and upon which too much stress cannot be laid, is never to give an opinion concerning a water whose history and surroundings are not thoroughly known.

The " free ammonia " in artesian wells is often excessive, under circumstances that make animal contamination an impossibility, and even rain-water, freshly collected after periods of long drought, will often exhibit properties calculated to mislead the analyst.

C. B. Fox gives the following determinations in pure *deep-well* waters:

	Free Ammonia.	Albuminoid Ammonia.
Well 230 feet deep	0.80	0.05
" 250 " "	0.76	0.04
" 300 " "	0.74	0.03
" 330 " "	0.37	0.06
" 385 " "	0.59	0.04
" "very deep"	0.41	0.07

This excess of free ammonia may be due either—

" 1. To entrance of rain-water;

" 2. To the beneficial transformation of harmful organic matter into the harmless ammonia, through the agency of sand, clay, and other substances which act on the water in a manner similar to the action of a good filter;

" 3. To some salt of ammonia existing in the strata through which the water rises; or,

"4. To the decomposition of nitrates in the pipes of the well. Mr. H. Slater suggests that the agent concerned in this reduction may, in the case of the deep-well waters, be the sulphide of iron which is found in the clay.

" We conclude, then, that the presence of free ammonia in such comparatively large quantities in these deep-well waters is due to the reduction of nitrates and nitrites by

sulphide of iron, or some kinds of organic matter, or some other agent, such oxidized nitrogen salts having been produced in past ages by the oxidation of organic matter." *

Free ammonia in deep-well water may, however, be derived from very objectionable sources; as when surface pollution is admitted because of cleavage and fracture cracks in friable rocks, and because of the "dip" of the strata being nearly vertical. The writer has seen a number of such cases.

Free ammonia is at times very high in the rain-water collected near large cities, and is liable to run higher in winter than in summer in such waters.

Dr. Drown points out the low values commonly found for both "ammonias" in ground-waters of good quality, and places that for albuminoid ammonia as rarely exceeding .025. He shows the influence of growing plants in reducing free ammonia, and quotes as illustration the great difference in this item in the water of Mystic Lake with change of season; thus two readings for free ammonia were:

August	.000
January	.573

A further point that is mentioned by the same observer is the liability to high free-ammonia readings in water from wells sunk in ferruginous,† swampy regions, because organic matter associated with oxide of iron furnishes in absence of oxygen favorable conditions for development of ammonia.‡

Wanklyn would clear away all difficulty of interpretation

* Fox, "Sanitary Examinations of Water, Air, and Food."

† Water passed through newly laid and rusty mains will often become materially changed in chemical character as well as in physical appearance. The influence of the iron rust is to reduce the nitrates present and increase the nitrites and free ammonia. A good water might thus be very readily condemned upon the analytical results alone did the analyst not know its antecedents.

‡ Mass. Board of Health, 1892, 324.

by holding that "albuminoid ammonia above .10 part per million begins to be a very suspicious sign; and over .15 it ought to condemn a water absolutely." Such a hard-and-fast rule is too severe for general application.

The author has seen many an excellent water greatly exceed these limits, particularly the brown waters supplying some of our Eastern towns. Many peaty waters, of proven wholesomeness, far exceed Wanklyn's limits. As has already been pointed out, waters of a brown or peaty character are always to be looked upon very narrowly, but some of them are unquestionably of good quality, and all of them would be condemned by the proposed standards.

The analyst must here again use his good judgment and decide whether or not there is natural and harmless cause for the high ammonia readings. The depth of color of the water will be a material guide to his decision.

The writer has recently analyzed the water from a mountain lake, situated far away from all possibility of sewage contamination, with the following results:

Free ammonia	.01
Albuminoid ammonia	.34

An excellent mountain stream that the writer recently recommended for a city supply, although but slightly colored, ran:

Free ammonia	.055
Albuminoid ammonia	.230

As a result of the analysis of fifteen drinking-waters from widely scattered sources, many of them city supplies, and all of them believed to be wholesome, Prof. Mallet gives figures for "albuminoid ammonia" that show an average of .152 part per million (highest = .325, lowest = .020).

Most of these would be unceremoniously condemned by the Wanklyn standard.

In his report to the Water Department of the City of Wilmington for 1882 Dr. Leeds, as the outcome of his experience in the analysis of American waters, says: "I should venture to propose, as an aid in determining whether a water-supply, derived (as most of our American cities' water-supplies are) from a flowing stream, is good and wholesome, the following highest limits as a standard of purity:

Free ammonia............	.01 to .12 per million
Albuminoid ammonia.....	.10 to .28 " "

Some years ago Dr. Smart pointed out that the *rate* at which the ammonia is evolved as of an importance at least equal to, if not greater than, the total amount of the same; he holds that: "*Gradual* evolution of albuminoid ammonia indicates the presence of organic matter, whether of vegetable or animal origin, in a fresh, or comparatively fresh, condition, while *rapid* evolution indicates that the organic matter is in a putrescent or decomposing condition."

This is entirely in accord with the present writer's experience. Thus the evolution of albuminoid ammonia was found as follows when analyzing the water of a mountain lake in which was a considerable growth of pond-lilies and other water-plants:

"Nessler" jar No. 1.....................	.0600
" " " 2......................	.0450
" " " 3......................	.0250
" " " 4......................	.0150
" " " 5......................	.0100
" " " 6......................	.0075
" " " 7......................	.0050
" " " 8......................	.0025
	.1700×2=.34

Water giving such results can be looked upon with much more favor than one presenting an albuminoid record such as the following:

"Nessler" jar No. 1	.1000
" " " 2	.0350
" " " 3	.0125
" " " 4	.0025
" " " 5	.0000
	.1500×2=.30

The two illustrations just given bring out very nicely another point advanced by Dr. Smart, namely, that if each jar's reading be about one half that of its predecessor the presence of peat, or of some equally permanent substance, is indicated; otherwise two thirds or three quarters of the total albuminoid ammonia would appear in the first jar.

Thus we see that the reading of results is entirely a question of opinion and sound judgment, and in this connection Mallet's conclusion cannot be read without marked interest; he says: "It is impossible to decide absolutely upon the wholesomeness or unwholesomeness of a drinking-water by the mere use of any of the processes for the estimation of organic matter or its constituents. I would even go further, and say that, in judging the sanitary character of a water, not only must such processes be used in connection with the investigation of other evidence of a more general sort as to the source and history of the water, but should even be deemed of secondary importance in weighing the reasons for accepting or rejecting a water not manifestly unfit for drinking on other grounds. There are no sound grounds on which to establish such general standards of purity as have been proposed." *

* "The question of a standard by which to judge the quality of any particular sample of water has frequently been discussed, but as yet no generally sat-

As a further aid to judgment the following analyses are given of sundry waters, in different parts of the country, condemned by the writer, several of them having caused disease. Also a few instances of waters of reliable quality. As elsewhere throughout the book, the results are in parts per million.

Number.		Free Ammonia.	Albuminoid Ammonia.	Chlorine.	N as Nitrate	N as Nitrite	Required Oxygen.	Total Solids.
1	Shallow city well................ ..	.025	.08	122	17.38	trace	1.4	554
2	City well 30 ft. deep (caused typhoid)	005	.035	146	10	0	1	769
3	Rock-drilled city well 57 ft. deep....	2.025	0	69	.025	0	.85	487
4	Spring-water (caused repeated cases of dysentery)..................	.01	.025	6	7	0	.8	35
5	Well near city.....................	.005	.045	24	9	0	1.1	215
6	Country well, strong salty taste....	.59	.245	2803	....	.25	....	5225
7	Town well.........................	.815	.075	36	0	trace	....	421
8	City well 250 ft. deep............	1.59	.395	102	0	trace	....	681
9	" " 255 " "	.31	.02	58	0	0	6.45	635
10	" " 226 " "	1.11	.08	199	0	0	1.3	779
11	Peaty mountain stream (autumn)...	.055	.23	2.4	0	0	7.4	34
12	Same stream in winter.............	.055	.117	1.9	.08	0	6.6	47.5
13	Mountain spring	.04	.048	4	1.404	trace	.3	228
14	Town supply, Elizabethtown, N. Y..	.048	.002	1.05	.05	0	.35	106
15	Large well-situated spring...	.005	.0075	3.8	.5	0	0	97
16	High mountain lake (peaty)........	.01	.34	2	0	0	6.6	43
17	Lake Erie, beyond sewage influence	.02	.135	.....	trace	trace	2.55	138

It will be observed that a goodly proportion of the impure waters quoted have figures for free ammonia higher than

isfactory conclusion has been arrived at. Several standards have indeed been proposed, but none has been generally adopted, and we cannot say that we regret the result. The laying down of any one general standard by which to judge the great variety of waters met with in different parts of the country and in different geological formations is, in our opinion, at once impossible and undesirable.

"By all means take into consideration and, on suitable occasions, make use of such general standards as have been laid down by chemists of high ability and large experience; but use these standards cautiously and with discrimination, and judge every case on its own merits. Judge by its conformity to, or divergence from, the general character of the waters of the district from which it comes; in other words, have district standards instead of a general standard." (A. Dupré, *Analyst*, April, 1883.)

those for albuminoid ammonia. This is always a suspicious sign.

One of the worst waters in the list, number two, would not have been condemned upon the ammonia items at all, thus showing the importance of judging from the completed analysis. Water number three, from Erie, Pa., is a rare case in the writer's experience, showing no albuminoid ammonia. The well is drilled in friable shale and within short distance of city privies. Water number four was from an isolated country summer residence. The water is materially higher in "chlorine" and "nitrates" than the local "normals," and is exposed to drainage from outhouse and stables.

Water number six was from Coxsackie, N. Y., and was sent for analysis; it is impossible to account for such an amount of chlorine except by assuming exceedingly careless sampling. Water number nine was from a well drilled into Hudson River shale, and was protected from immediate surface drainage. The chlorine rose from 58 to 64.3 some fifteen hours after emptying a bushel of salt into a privy-vault fifty feet distant.

Water number ten was from a drilled well, in shale rock, constructed with much more care than usual. Extreme precautions were taken to shut out all immediate surface drainage, and they were undoubtedly successful. Nevertheless the neighboring privies contributed their seepage, raising the "free ammonia" and "chlorine" tremendously above the local "normals." Such results show us how unsafe it is to trust to the purity of rock-drawn water, when, owing to the seamy character of the rock, and the direction and angle of its "dip," almost direct connection may be established between the bottom of the well and the surrounding sources of surface pollution.

A comparison of waters eleven and twelve shows the in-

fluence of freezing weather in tying up the fountains of "peaty" contamination.

In working the "albuminoid ammonia" process it is of importance that sundry minor details should be observed in order that concordant results may be obtained; attention is therefore called to the following points:

1. Use a tubulated glass-stoppered retort, and connect the same with the condenser by large-bore soft-rubber tubing. The retort-neck should project 3 to 4 c.m. into the condenser-tube, and the rubber be drawn over both so as to make a perfectly tight joint. Particularly avoid the paper packing recommended by Wanklyn, as the same cannot but lead to loss of ammonia.

Trouble is often experienced with certain waters, owing to their tendency to "bump," and thus permit of a portion of the retort contents being mechanically carried over into the condenser-tube. We avoid this difficulty by bending the neck of the retort through an angle of about twenty degrees at a point a little beyond its middle. Upon fitting such a bent retort to the condenser the contained liquid rests well towards the back, and splashing over is practically impossible.

The condensers used in this laboratory are galvanized iron tanks 14 inches deep, 14 inches broad, and 20 inches long. They rest upon wooden benches of the same superficial area, and 12 inches high. The two condensing-tubes for each tank are of block tin, $\frac{1}{4}$ inch inside diameter, and enter the side of the tank $1\frac{1}{2}$ inches from the top, dip immediately to near the bottom, and then slope gently to the exit-point one inch above the bottom on the opposite side. Just before entering the tank the tin tube is suitably enlarged to receive the neck of the retort.

The "Nessler" jars used are long and narrow, being $11\frac{1}{2}$ inches total length, and $8\frac{1}{2}$ inches from the bottom to the 50-

c c. mark. A very convenient lamp for heating the retorts is the broad flat " Bunsen " ($3\frac{1}{2}$ inches diameter) with numerous small jets over its surface.

2. Keep the current of cooling water passing through the condenser at a velocity such that the difference between the temperature of the inflowing and outflowing water shall not exceed one degree centigrade.

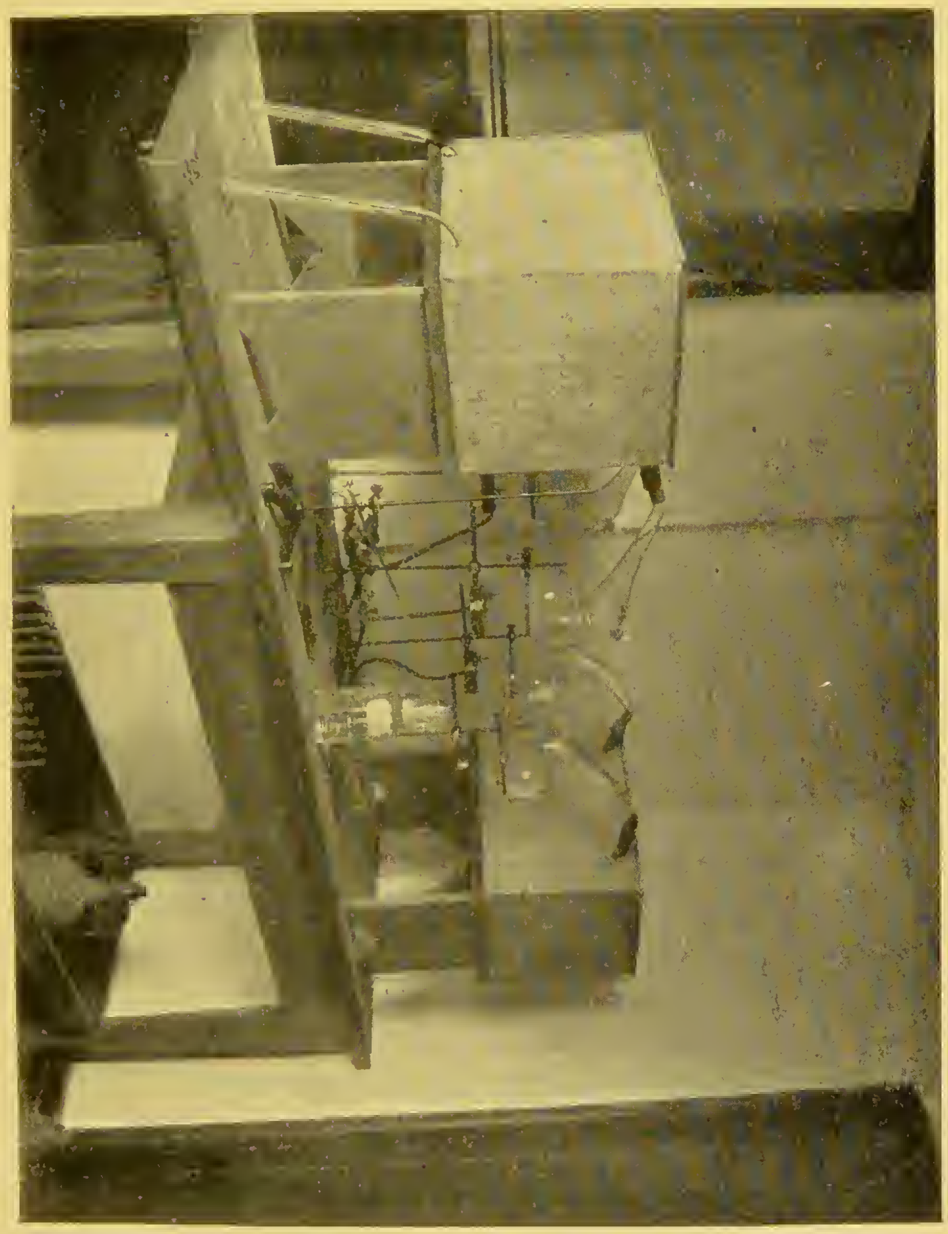
This is very easily done with condensers as large as those described.

3. Be very careful to have the " standard ammonia " solutions and the distillates at the same temperature when the " Nessler " solution is added; otherwise equal strengths of ammonia would strike different shades of color and produce error. This end is best achieved by cooling the prepared standards in the same running tap-water that is used for the condensers.

4. Even with the utmost precaution some ammonia will be lost through imperfect condensation. Dr. Smart found that " the varying percentages of loss may be taken as representing the heating power of the flame used, or, inversely, the time occupied in distillation."

My assistant, Mr. Bowman, obtained the following different results for " free ammonia " from the same tap-water by varying the time required to fill a 50-c.c. " Nessler " jar:

Jar Number.	5 Minutes.	10 Minutes.	15 Minutes.	20 Minutes.
1............	.0050	.0075	.0250	.0250
2............	.0025	.0050	.0075	.0075
3............	trace	.0050	.0060	.0065
4............	0	trace	.0025	.0025
5............	0	trace	trace	trace
6............	0	0	0	0
	.0075	.0175	.0410	.0415
	2	2	2	2
	.0150	.0350	.0820	.0830



SHOWING RETORTS, CONDENSERS, AND "NESSLER" JARS FOR "ALBUMINOID AMMONIA" PROCESS.

Repeating the same experiment, using a prepared water containing .15 part ammonia per million, the results were:

Jar Number.	5 Minutes.	10 Minutes.	15 Minutes.
1	.0450	.0450	.0500
2	.0150	.0125	.0150
3	.0035	.0025	.0050
4	0	.0025	0
5	0	.0025	0
6	0	0	0
	.0635	.0650	.0700
	2	2	2
	.1270	.1300	.1400

The amount of ammonia being therefore a function of the time employed, it becomes necessary to eliminate, so far as may be, any error that might arise from this source by conducting all distillations as nearly as possible at the same rate. So manage the lamp, therefore, as to fix the time required for the distillation of 50 c.c. at fifteen minutes.

5. It is not sufficient to note the *total* amount of "free" and "albuminoid" ammonias, but the full notes of the "Nesslerizing" process must be retained, that the *rate* at which the ammonia passes over may be determined. As before stated, important findings may be deduced therefrom. Dr. Smart believes "that a water which in the third or fourth measure of its distillation gives a persistent evolution of 'free ammonia,' which is followed in the progress of the experiment by a persistence of twice that quantity of 'albuminoid ammonia,' probably contains *urea*." He is, as the result of investigation, led to add that a water which yields such results will contain "as many parts per million of urea

as there are hundredths of a milligramme of 'albuminoid ammonia' persisting in each measure.'' *

In order to test the constancy of results when the conditions governing the work are strictly constant three samples of the same water were run for "free" and "albuminoid" ammonias with the following results:

	Free Ammonia.	Albuminoid Ammonia.
A	.0075	.0275
	.0025	.0225
	trace	.0075
	0	.0035
	——	.0025
	.0100 × 2 = .020	trace
		——
		.0635 × 2 = .127
B	.0075	.0325
	.0020	.0230
	trace	.0075
	0	.0025
	——	trace
	.0095 × 2 = .019	0
		——
		.0655 × 2 = .131
C	0080	.0270
	.0025	.0225
	trace	.0100
	trace	.0030
	0	.0025
	——	trace
	.0105 × 2 = .021	——
		.0650 × 2 = .130

6. As already stated, do not observe the tint of a "Nesslerized" solution until five minutes after the addition of the reagent. After the expiration of that time the color may be considered constant, no further material change taking place in twelve hours. Consequently, in the case of the examination of many successive samples, the "Nesslerized" standard solutions need not be made up for each water, but those prepared in the morning may be used during the entire day,

* It must be noted, however, that Dr. Smart allows *twenty* minutes for the filling of a 50-c.c. "Nessler" jar.

proper care being taken to protect them from the action of the atmosphere by covering them when not in use.*

7. As has been already pointed out, water-samples will not keep many days; whence the necessity for a speedy analysis after the collection is once made. The changes which take place in water upon keeping have been carefully investigated by Smart and Mallet,† and although their opinions upon this topic are not so full as the rest of their work, they are nevertheless very convincing.

Investigations tending in the same direction and leading towards the same results were also undertaken in this laboratory before Mallet's report appeared.

The tendency is for "free ammonia" to disappear upon keeping; and, as a rule, the "albuminoid ammonia" also diminishes. From observations made upon the appearance and disappearance of nitrites there seems to be little doubt but that the loss of "free ammonia" is to be accounted for by a process of nitrification. Nitrites are formed at the expense of the ammonia, and they, in their turn, are converted into nitrates by further oxidation. Nitrogenous organic matter in water may be considered as belonging to two classes: *first*, "that which passes readily into the condition of 'free ammonia' through purtrefactive agencies," and which is consequently easily acted upon by the permanganate solution; and, *second*, that which is more stable, and from which no ammonia is evolved during distillation with the above reagent. Upon standing for any considerable time this latter class becomes slowly converted into the less stable

* Standards of .01, .02, .03, .04, .05, .06, .07, .08, and .09 m.g. of NH_3 in 50 c.c. water were prepared and "Nesslerized," and after an interval of three days were compared with fresh preparations. It was observed that .03, .05, and .07 had not changed. The remainder had darkened to a very slight degree, but less than .0025 in each case.

† Nat. Board of Health, 1882.

variety,* which in its turn is gradually converted into "free ammonia," the ammonia in turn becoming finally nitrified, as already stated. Thus we have a perfect system of changes, from the stable nitrogenous organic matter on the one hand, to the fully oxidized nitrate on the other. Of course we are citing but a typical case, and must be prepared to see all manner of departures therefrom in special instances, according as the character and amount of materials and the nature of the environment may differ.

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* It is good practice to redetermine the albuminoid ammonia after the sample has stood a number of days. By such means an idea may be obtained of the stability of the nitrogenous organic material whence such ammonia is derived.

OXYGEN-CONSUMING CAPACITY.

("REQUIRED OXYGEN.")

The third and last method for estimation of organic matter that we shall touch upon is Kubel's modification of the old permanganate process of Forschammer. The original mode of procedure was published in 1850 and "consisted merely in adding a solution of potassic permanganate of known strength, without any other reagent, to a measured amount of water to be examined, until the liquid had acquired a faint permanent tinge, and then noting the quantity used. It was afterwards ascertained that more uniform results could be obtained, and with less expenditure of time, by causing the permanganate to act in the presence of free acid or free alkali." Kubel uses a boiling temperature.

The form of determination recommended is that employed by Dr. Smart. The necessary solutions are:

Standard Potassic Permanganate Solution. — Dissolve 0.3952 gramme of the salt in one litre of distilled water. Each cubic centimetre of such solution will contain 0.1 m. g. of oxygen available for oxidation. The available oxygen of the permanganate in presence of sulphuric acid may be represented by the equation

$$K_2Mn_2O_8 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 3H_2O + 5O.$$

Solution of Oxalic Acid ($H_2C_2O_4 \cdot 2H_2O$).—Dissolve 0.7875 gramme of the crystallized acid in one litre of distilled water. This solution if titrated against the permanganate solution (while hot, and in presence of H_2SO_4) should correspond to it c.c. for c.c. The equation is

$$K_2Mn_2O_8 + 3H_2SO_4 + 5(C_2H_2O_4 \cdot 2H_2O) = K_2SO_4 + 2MnSO_4 + 10CO_2 + 18H_2O.$$

Ten c.c. of the oxalic acid solution, diluted with 200 c.c. pure water and 10 c.c. of the dilute sulphuric acid, should be titrated, boiling, with the standard potassic permanganate solution, and the amount of the latter required should be recorded.

Dilute Sulphuric Acid.—One part of the strong acid to three of distilled water.

Determination.—Place 200 c.c. of the water under examination in a porcelain casserole; add 10 c.c. of the dilute sulphuric acid, and run in the standard permanganate solution from a burette until the water has a very marked red color. Boil *ten minutes*, adding more permanganate from the burette from time to time, if necessary, in order to maintain the intensity of red color observed at the start. Do not let the color fade nearly out, and then add the permanganate in quantity, at once, but strive to keep the color as nearly constant as possible by gradual addition.

Remove the lamp, add 10 c.c. (or more, if necessary) of the oxalic acid solution to destroy the color, and then add the permanganate solution from the burette until a faint pink tinge again appears. From the total permanganate used deduct that corresponding to the 10 c.c. oxalic acid employed, and from the remainder calculate the milligrammes of "available oxygen" consumed by the organic matter present in the water. Correction must be made for nitrites, ferrous salts, or hydrogen sulphide if any of them be present.

Standards.—As this determination deals principally with the organic carbon present, the readings are naturally high in the cases of brown peaty waters, and surface-waters carrying organic matter in suspension. (See the list of analyses, page 397.)

Leeds's for *American rivers*................ 5 to 7

Averages from determinations by Dr. Smart:

Impure (14 samples)	5.880
Doubtful purity (5 samples)	3.073
Medium purity (15 samples)	1.414
Pure (18 samples)	0.581

The severe character of the following French classification is due to the fact that spring-waters are popular in France, and surface-waters are filtered before use:

Very pure	1
Potable	2
Suspected	3 to 4
Impure	above 4

LEAD AND COPPER.

It at times becomes necessary to examine water for these poisonous metals, and the ease with which their dark sulphides may be formed provides a ready method. (Miller.)

Prepare a standard solution of lead nitrate, $Pb(NO_3)_2$, by dissolving 1.5990 grammes of the salt in one litre of distilled water. Each cubic centimetre will contain 1 m.g. metallic lead.

Place the water in a 100-c.c. "Nessler" jar; add 2 drops of concentrated HCl, followed by 1 c.c. of colorless ammonium sulphide, and match the tint by operating with measured amounts of the standard lead solution diluted to 100 c.c.

This will not, of course, distinguish between copper and lead, but, inasmuch as each is objectionable, distinguishing is really not necessary.

In order to test the action of the water upon *lead pipe* permit it to remain in contact with both bright and dull lead (in separate vessels) for twenty-four hours, and then examine the water as above.*

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* As a test for lead Blyth suggests the use of an alcoholic solution of cochineal, which strikes a distinct bluish tint with water containing lead. One hundred c.c. Nessler jars are convenient vessels for use in making the test, and two of them should be employed, one containing the water under examination, and the other a water known to be lead-free. One c.c. of the cochineal solution should be added to each jarful of water. Copper will produce a color similar to lead in this test. (*Analyst*, IX. 41.)

IRON.

This metal is objectionable if in considerable quantity,* particularly in water to be used for washing white goods, and for dyeing. To determine its quantity acidify a suitable volume of the water with aqua regia; concentrate to 100 c.c.; place in a 100-c.c. "Nessler" jar; add 2 c.c. of ammonium sulpho-cyanate solution, and compare the depth of color produced with known amounts of standard iron solution diluted to 100 c.c. and similarly treated with ammonium sulphò-cyanate solution.

The *standard iron solution* is prepared by dissolving 0.1 gramme pure iron in a little HCl to which a few drops of HNO_3 have been added, and then diluting to one litre.

Iron which tends to increase in a well-water as the draught upon the underground supply grows in volume is a discouraging symptom; for the probabilities are strong that the water will eventually become unfit for use without removal of the ever-increasing iron.

* Wanklyn believes that a drinking-water should not contain over 3 parts of iron per million.

Parmentier finds alumina in all natural waters. (*Chem. News*, LXVI. 85.)

ZINC.

Zinc is not a cumulative poison, but its presence in a water is nevertheless distinctly objectionable. Galvanized iron pipe is attacked by certain waters, and spring-water is at times zinc-bearing, as has been especially noticed in Southern Missouri.*

For the determination of the metal it is best to evaporate considerable of the water, and make the usual gravimetric determination after precipitation as a sulphide.

For qualitative purposes Allen's test is useful: Render the water slightly alkaline with ammonia hydrate; boil; filter, and add a few drops of potassium ferro-cyanide. A white precipitate will form in presence of a trace of zinc.

Arsenic occurs in some waters naturally, and *chromium* may be present from industrial waste. Should the presence of these elements be suspected, their determination should be undertaken, in the concentrated water, by the usual quantitative methods.

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* Zinc-bearing spring-water from Missouri:

	Parts per Million.		Parts per Million.
$PbSO_4$	trace	$CaSO_4$	109.9
$CuSO_4$	0.5	$MgSO_4$	19.0
$CdSO_4$	0.9	K_2SO_4	5.6
$ZnSO_4$	297.7	Na_2SO_4	5.9
$FeSO_4$	1.6	$NaCl$	4.3
$MnSO_4$	6.3	$CaCO_3$	72.0
$Al_2(SO_4)_3$	2.5	SiO_2	13.7
			539.9

(Hillebrand, Bul. 113, U. S. Geol. Sur.)

PHOSPHATES.

T. L. Phipson holds that phosphates are never present in more than minute traces in waters fit for domestic use, but that in contaminated waters they are "always present," a statement with which it is hard to fully concur.

To determine them he takes a large measure of the water, adds a little alum solution, followed by a few drops of ammonia, and then makes the solution acid with acetic acid. The aluminum phosphate is filtered off, dissolved in nitric acid, and precipitated with ammonium molybdate solution in the usual way.*

* *Chem. News*, LVI. 251.

DISSOLVED GASES.

Oxygen.—No process with which the author is acquainted for the determination of the dissolved oxygen gives such desirable results as that devised by M. Albert-Levy, of the Montsouris Observatory, Paris. It is as follows:

A pipette of about 100 c.c. capacity is provided with an upper and a lower stopcock, and the capacity of the same between the stopcocks is determined. Above the upper stopcock the tube is expanded into a short, cylindrical funnel. The pipette is completely filled with the water to be examined by immersion with both cocks open. The cocks having been closed, the pipette is wiped off and fixed in a suitable clamp, with its lower point dipping into a little dilute sulphuric acid. Two c.c. of dilute potassic hydrate solution are placed in the funnel and, by careful opening of the cocks, introduced within the pipette without the admission of air. After washing the funnel 4 c.c. of a solution of ammonium ferrous sulphate are placed therein, and, by similar means, also admitted within the pipette. In presence of the alkaline solution the oxygen dissolved in the water will immediately oxidize the ferrous salt to ferric, and a mixture of the two hydrates will shortly settle to the bottom after gentle agitation. After again washing the funnel 2 c.c. of sulphuric acid (equal parts acid and water) are placed therein, and the upper stopcock alone is opened. The higher gravity of the acid will cause it to slowly enter the pipette, where it will acidify the contents and dissolve the hydrates of iron. The contents and washings of the pipette, together with the acid from the beaker into which the lower extremity of the pipette has dipped, are now turned into a flask and titrated with the standard solution of potassic permanganate already prepared on page 406. A

blank is now titrated containing a mixture of 100 c.c. of the water, 2 c.c. of the sulphuric acid, 2 c.c. of the potassic hydrate solution, and 4 c.c. of the ammonium-ferrous sulphate solution. The difference between these two titrations (acid reaction having prevented oxidation in the second instance) will give the amount of ferrous salt oxidized by the oxygen dissolved in the water. The volume of the water operated upon will be the volume of the pipette (V) less the volumes of the alkaline and iron solutions, namely:

$$v - (2 + 4) \text{ c.c.}$$

M. Albert-Levy makes further and valuable use of this method beyond the mere estimation of dissolved oxygen. Some time since he pointed out that various waters behave very differently when exposed to the light, so far as their contained oxygen is concerned. Some quickly lose their oxygen, thus:

	M.g. Oxygen per Litre.
Seine water	10.6
Same after 8 days	7.2
Same after 15 days	None

Others act in a manner quite the reverse, thus:

Vanne water	11.1
Same after 9 days	20.2
Same after 60 days	39.7

These different results arise from the greater or smaller quantities of organic life present, some endowed with chlorophyll and some not possessing such constituent—algæ and bacteria, for example.

Water heavily charged with microbes quickly loses its oxygen; while the greater number of algæ, on the contrary, contribute oxygen by evolving it under the influence of

light. Albert-Levy conceived the idea of making use of this difference in action to establish an approximate measure of the quantity of bacteria present.

He makes an immediate determination of the dissolved oxygen present.

A second sample of the water is then introduced into a glass-stoppered bottle, which it completely fills, and is placed in the dark, at a constant temperature of 33° C. for forty-eight hours. Such conditions are favorable for bacterial activity, while algæ-growth is stopped. At the end of the time stated the dissolved oxygen is again estimated, and the amount found to have been lost will be in a measure proportional to the bacterial contents of the water.

The loss of oxygen, divided by the amount of it originally present, is styled the "*coefficient of alterability*."

Such use of Albert-Levy's method as above described is herewith graphically shown. The distances apart of the two curves for dissolved oxygen indicate the monthly variations in number of bacteria present in the water. The influence of surface-washing in spring and autumn is here well shown in increased bacteria, as is also the comparative bacterial purity in midsummer.*

The determination of other gases present in solution is not commonly of sufficient value to repay the expenditure of time required for such work.

Should it be decided upon, however, to include an estimation of carbon dioxide in the analysis, Seyler's method, as given in *Chemical News*, LXX. 104, is to be recommended.

An odor like that of sulphuretted hydrogen must not be taken as proof positive of the presence of that gas in a water, inasmuch as mixtures of sundry hydrocarbons will often greatly mislead the sense of smell.

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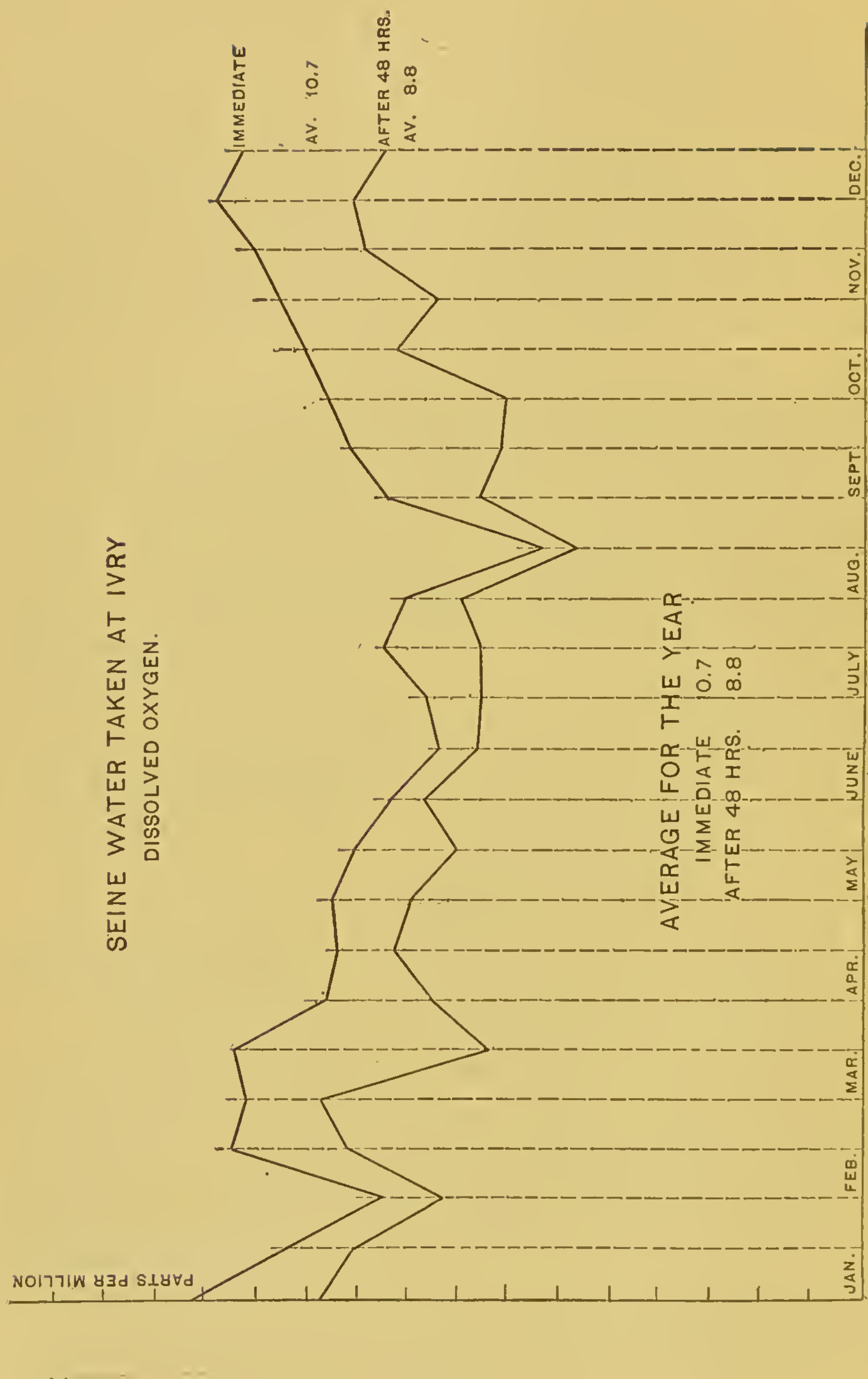
* See page 195.


SEINE WATER TAKEN AT IVRY
DISSOLVED OXYGEN.
IMMEDIATE
AV. 10.7
AFTER 48 HRS.
AV. 8.8
AVERAGE FOR THE YEAR
IMMEDIATE 10.7
AFTER 48 HRS. 8.8
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
PARTS PER MILLION

The author has in mind such a case from Northern New York, and also another from Kansas, which latter water, by the way, contains much iron.

According to Bunsen, one litre of water at 760 m.m. pressure may contain:

	At 0° C.	At 10° C.	At 20° C.
Oxygen	41 c.c.	33 c.c.	28 c.c.
Nitrogen	20 "	16 "	14 "
Carbon dioxide	1797 "	1185 "	901 "

What is generally known as the "Michigan standard of the purity of drinking-water," as specified by the Michigan State Laboratory of Hygiene, is here given:

"1. The total residue should not exceed 500 parts per million.

"2. The inorganic residue may constitute the total residue.

"3. The smaller amount of organic residue the better the water.

"4. The amount of earthy bases should not exceed 200 parts per million.

"5. The amount of sodium chloride should not exceed 20 parts per million (i.e., "chlorine" 12.1 parts per million).

"6. The amount of sulphates should not exceed 100 parts per million.

"7. The organic matter in 1,000,000 parts of the water should not reduce more than 8 parts of potassium permanganate (i.e., "required oxygen" 2.2 parts per million).

"8. The amount of free ammonia should not exceed 0.05 part per million.

"9. The amount of albuminoid ammonia should not exceed 0.15 part per million.

"10. The amount of nitric acid should not exceed 3.5 parts per million (i.e., "N as nitrate" .9 part per million).

"11. The best water contains no nitrous acid, and any water which contains this substance in quantity sufficient to be estimated should not be regarded as a safe drinking-water.

"12. The water must contain no toxicogenic germs as demonstrated by tests upon animals.

"The water must be clear and transparent, free from smell, and without either alkaline or acid taste, and not above 5 French standard of hardness."

Such a standard is much too severe for general use. The specifications for the new supply for Jersey City were based thereon, and it was not surprising that they were declined by the contractors. As has been so often said, a general standard of purity is impossible. Each case should be judged upon its own merits, after a careful study of all the relating facts.

The following form of water report is in use at the University of Arizona:

"ANALYSIS OF WATER from............................

To Determine Value for Irrigation or Boiler Purposes.

Total Residue on Evaporation, at temperature of boiling water................
Loss by ignition at low red heat, combined water and organic matter..............
Color on heating, showing presence of organic matter...........................
Residue soluble in water, common salt, Glauber's salt, etc.......................
Residue insoluble in water, but soluble in acid, lime, etc.........................
Residue insoluble in acid, silica—sand...

ANALYSIS OF WATER-SOLUBLE RESIDUE.

Sodium chloride (*common salt*)...
Sulphates of sodium, magnesium, and potassium, Glauber's salt, etc.............
Sodium carbonate (*sal-soda*)...

ANALYSIS OF ACID-SOLUBLE RESIDUE.

Carbonates of lime and magnesia...
Sulphate of lime (*gypsum*)...

RESIDUE INSOLUBLE IN ACID.

Silica (*sand*)...

The interest of a water-analysis centres in two points—the *amount* and *character* of total residue. Other things being equal, the less residue the better for the purposes of irrigation or boiler use.

For Boiler Use.—A large amount of insoluble residue causes an incrustation in the boiler. This incrustation is harder and more difficult to remove in case the water contains much gypsum. Large amounts of soluble solids, especially carbonate of soda, cause frothing.

For Irrigation Use.—The amount of residue insoluble in water has no harmful effect. Residue soluble in water remains in the soil as soluble salts or alkali Of these common salt and soluble sulphates which cause white alkali are harmless, except in large quantities. Carbonate of soda (sal-soda) which causes black alkali is exceedingly corrosive to plant-growth, and in quantities larger than two parts per hundred thousand must be looked on with suspicion. Land irrigated with such waters will be benefited by an application of one hundred pounds per acre of gypsum. Water having gypsum never contains carbonate of soda.

Water results are best reported in "parts per million," as already stated, but, at times, a demand will be made for a report stated in "grains per U. S. gallon," and to facilitate conversion from one form to the other the table given herewith was prepared:

CONVERSION OF "MILLIGRAMMES PER KILOGRAMME" INTO "GRAINS PER U. S. GALLON" OF 231 CUBIC INCHES.

One U. S. gallon of pure water at 60° F., weighed in air at 60° F., at atmospheric pressure of 30 inches of mercury, weighs 58,334.94640743 grains.*

Parts per Million.	Grains per U. S. Gallon.	Parts per Million.	Grains per U. S. Gallon.	Parts per Million.	Grains per U. S. Gallon.	Parts per Million.	Grains per U. S. Gallon.
1	0.058335	26	1.516708	51	2.975082	76	4.433456
2	0.116670	27	1.575043	52	3.033417	77	4.491791
3	0.175005	28	1.633378	53	3.091752	78	4.550126
4	0.233340	29	1.691713	54	3.150087	79	4.608461
5	0.291675	30	1.750048	55	3.208422	80	4.666796
6	0.350010	31	1.808383	56	3.266757	81	4.725130
7	0.408344	32	1.866718	57	3.325092	82	4.783465
8	0.466679	33	1.925053	58	3.383427	83	4.841800
9	0.525014	34	1.983388	59	3.441762	84	4.900135
10	0.583349	35	2.041723	60	3.500097	85	4.958470
11	0.641684	36	2.100058	61	3.558432	86	5.016805
12	0.700019	37	2.158393	62	3.616766	87	5.075140
13	0.758354	38	2.216728	63	3.675101	88	5.133475
14	0.816689	39	2.275063	64	3.733436	89	5.191810
15	0.875024	40	2.333398	65	3.791771	90	5.250145
16	0.933359	41	2.391733	66	3.850106	91	5.308480
17	0.991694	42	2.450068	67	3.908441	92	5.366815
18	1.050029	43	2.508402	68	3.966776	93	5.425150
19	1.108364	44	2.566737	69	4.025111	94	5.483485
20	1.166699	45	2.625072	70	4.083446	95	5.541820
21	1.225034	46	2.683407	71	4.141781	96	5.600155
22	1.283369	47	2.741742	72	4.200116	97	5.658490
23	1.341704	48	2.800077	73	4.258451	98	5.716825
24	1.400039	49	2.858412	74	4.316786	99	5.775159
25	1.458373	50	2.916747	75	4.375121	100	5.833494

*See article by the author on "The U. S. Gallon" in *Am. Druggist*, January, 1888.

CHAPTER XI.

BACTERIOLOGICAL EXAMINATION OF WATER.

APROPOS of the recent articles upon the question of chemical *vs.* bacteriological examination of potable water which have appeared in the English papers, it is noteworthy that there is a growing tendency among physicians and civil engineers to belittle the chemist's opinion regarding the potability of a water, and to pin their faith exclusively upon what the bacteriologist may have to say upon the subject. This feeling is strengthened by the publication of the results of such trials as that undertaken by the London Local Government Board, in which, it will be remembered, water-samples purposely inoculated with typhoid germs were sent for analysis to one of England's leading chemists and were by him pronounced pure.

Those who set special value upon such a "test" of methods as the above, and who consider it quite final as showing the inability of chemistry to detect pollution in a liquid which the bacteriologist would instantly pronounce very foul, should remember that such a sample of water could not be found in practice, and that the very conditions under which it was prepared eliminated the chemical items indicating pollution, while they increased tremendously the signs governing the bacteriological side of the case.

The bacteriologist sought for the Eberth bacillus, and very naturally quickly found it in a water purposely sown with the germ.

The chemist looked for those elements which always

occur in sewage-laden water, whether the sewage be from sources of disease or otherwise, and, not finding them, he pronounced the water to be free from sewage addition.

Sewage, as it occurs in practice, contains an immense deal of material other than that productive of disease, and it is upon just this comparatively harmless, but constantly present, material that the chemist relies for the indication upon which he bases his opinions.

He is unable to say whether or not a sewage-laden water is disease-bearing on any particular date, for to him all sewage is alike, but he condemns the water, for the reason that, although it may be harmless to-day, it is impossible to predict what may be its condition to-morrow.

Very recently the author was requested to make a bacteriological examination of the water of a certain well in order to determine if it were affected by neighboring cess-pools.

The physician who made the request was impressed with belief in the paramount value of such an examination and the comparative uselessness of chemical analysis.

It is quite certain that, had his suggestion been followed, the search would have been in vain for any specific microbe, but inasmuch as upon chemical analysis the "chlorine" was found to run twenty-four parts per million, which is about ten times the local "normal," and the "nitric nitrogen" nine parts per million in place of 0.116, the water was condemned offhand without going further.

There is simply no comparison between the two methods in question for water problems of this class, and the value of chemistry is still more pronounced in those instances where it is possible to introduce common salt or lithium chloride into a source of suspected pollution, and then look for increased chlorine or presence of lithium in the water of the well. In legal cases touching upon this point of contami-

nation of wells, by cemeteries, for instance, the chemical testimony is especially strong.

In the matter of determining the suitability of a stream for city supply the services of the bacteriologist should be unquestionably secured, but it is doubtful if his report can be considered of more importance than that of the chemist. Chemical analysis, by comparing the water taken at the site of the proposed intake with that from the same stream above all points of possible pollution, can indicate whether or not up-stream contamination is felt at the lower point; nor is it necessary that the polluting sewage be from pathogenic sources in order that its presence may be recognized. As Dr. Dupré has pointed out, chemistry in such cases anticipates what may happen in the future, and, by timely advice, may prevent an outbreak of disease, while, on the other hand, the discovery of disease-germs in a water is only possible after the water has become infected.

Bacteriology is of especial value, and greatly superior to chemistry, for the testing of filters and watching any variation in their efficiency.

For this purpose the simple count of germs per cubic centimetre is most valuable, and differentiation is a secondary matter; for the assumption is a just one that a filter which will remove the harmless bacteria will take out the objectionable ones as well.

It is very far from the writer's desire to decry the value of bacteriology, but he cannot but feel that in their enthusiasm over the great triumphs of the new science the people at large have gone slightly "bacteria mad," and are apt to expect more than can be furnished by the means and information now available.

When one considers the magnitude of the bacteriological field, it is manifestly out of the question, in a book of this scope, to go beyond a simple enumeration of the bacteria

present per cubic centimetre of a water under examination, leaving the problem of differentiation to be discussed by writers upon bacteriology.

"It has been asserted that the presence of a large number of micro-organisms is no criterion of the quality of water, and that a mere enumeration of colonies is of little or no value. Without a thorough knowledge of all the accompanying conditions such evidence is certainly insufficient, though, speaking in a general way, it may be accepted that numerous bacteria indicate the existence of a sufficient quantity of food, which, in water, is commonly of the nature of sewage. 'Wheresoever the carcass is, there will the eagles be gathered together'; or, to render the illustration more congruous, it may be said that a few weeds of a particularly hardy species may be found on poor soil, but, for number and variety, the ground must be rich.

"It is for the comparative examination, at different times and localities, of a water of known character, and for the detection of sewage contamination, that a bacterial enumeration is most useful." *

This is the same point which has already been made, when it was held that such examination is of great value for the watching of a filter-plant.

Culture-jelly.—The following method of preparation of the jelly has been found very excellent by the writer. It was originally given him by Dr. Beebe, of the New York City Board of Health:

Take one pound of lean beef, chop it fine, and let it soak overnight in 700 c.c. water. Strain through a cloth and make up to one litre with water. Add:

---

* *Engineering News*, October 4, 1894.

Gelatine (best French)...........	100	grammes
Peptone (Witte's)................	10	"
Common salt......................	5	"

Heat in a double-walled "oatmeal-boiler" at a temperature between 35° and 40° C. until all is dissolved, then make very slightly alkaline by addition of sodic hydrate solution. Add the white of one egg, previously shaken up with about its own bulk of water, and stir thoroughly. Heat as rapidly as possible to boiling, stirring occasionally. Cover the mixture and keep the water in the outer vessel boiling during fifty minutes.

Filter, with the use of the hot-water funnel, into test-tubes, placing about 10 c.c. in each tube. Plug the tubes with cotton and sterilize them in an Arnold's sterilizer for *fifteen minutes* on three successive days.

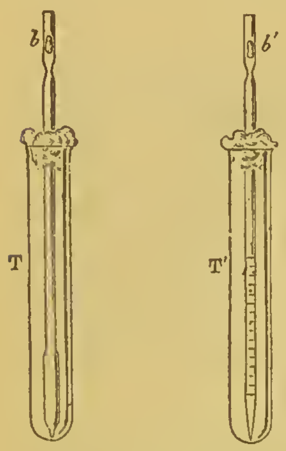
It is best to make but one litre of the jelly at a time, as it does not keep well in stock. Old jelly has a tendency to become acid in reaction, which is unfavorable to the growth of certain bacteria. Some that is six months old at the present writing still gives good results, but its use is not to be recommended.

Empty glassware is best sterilized by a single heating for one hour to 180° to 200° C.

The 1-c.c. pipettes used for the measurement of the water should be plugged with cotton near the end which is placed in the mouth; the whole pipette should then be placed in a suitable glass tube containing a cotton plug in its open end; through such cotton plug the large end of the pipette is permitted to protrude.

Pipettes so prepared may be sterilized, and maintained so in stock.

Water-samples are most conveniently taken in bulbs of glass ($2\frac{1}{4}$ inches diameter) with long thin stems, similar to the stock article in use for specific gravity determinations. These bulbs can be sterilized by the direct Bunsen flame and sealed while hot. Upon afterwards breaking off the point of the stem under water the water will enter the vessel because of the partial vacuum, and the stem can be at once resealed in a candle-flame.



Such bulbs are very convenient for taking deep samples, as the point of the stem can be broken by a separate string while the bulb is held by the sinking-apparatus.

During transportation the bulbs filled with water-samples should be packed in ice.

Upon arrival at the laboratory the base of the stem is cut through with red-hot carbon; 1 c.c. of the water, after agitation, is transferred, by means of a sterilized pipette, to a tube of culture-jelly (the jelly having been previously liquefied by immersing the tube in warm water, and the cotton plug having been held for a moment in the Bunsen flame); mixing is accomplished by tilting the tube forward and back, and the mixture is then quickly poured into a sterilized Petri dish ($3\frac{1}{2}$ inches diameter). After the jelly has again hardened the dish should be maintained, in the dark, at a temperature of about 22° C.

Each individual bacterium, finding itself imbedded in material supplying abundance of food, proceeds to surround itself by a multitude of its offspring, until at length the "colony" so produced becomes large enough to be seen by the naked eye. These colonies, each of which corresponds to one original bacterium, are of various sizes, as shown in

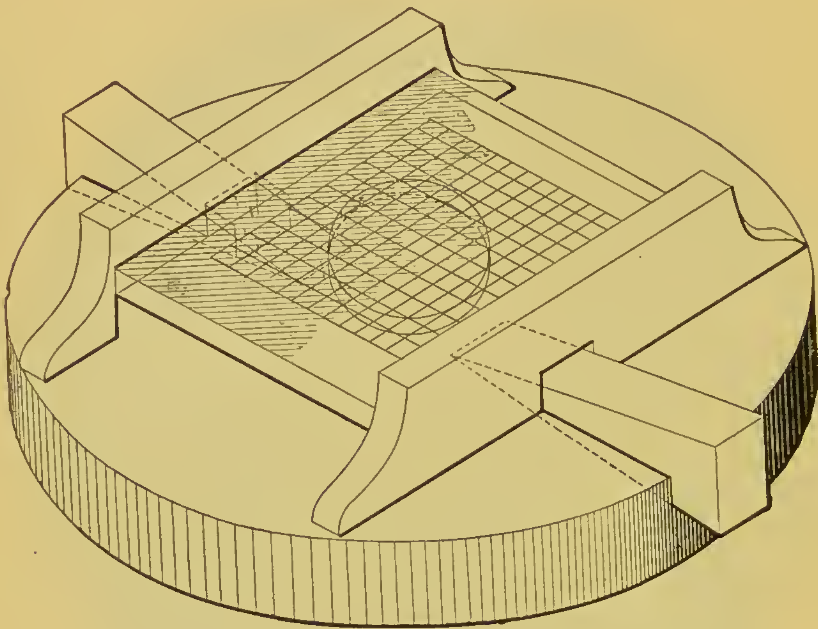
the accompanying illustration. Some of them do, and others do not, liquefy the gelatine.

PETRI DISH, SHOWING COLONIES OF BACTERIA GROWING IN "CULTURE-JELLY." (Ohlmüller).

Counting the colonies of bacteria is usually undertaken about forty-eight hours after the sowing, but it is well to delay it longer or to count sooner, according as the danger may be less or greater of the colonies growing into each other and thus confusing the count.

When the number of the bacteria colonies is large, counting must be done with the aid of a ruled glass plate. The best device for this purpose with which the writer is familiar is one invented by a student of his, Mr. J. A. McPherson. It is a modification of the older form of counting-apparatus,

but with a fixed upper plate of ruled glass and a lower supporting plate moved vertically by wedges.



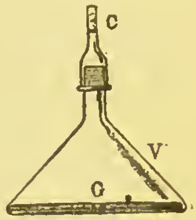
IMPROVED APPARATUS FOR COUNTING COLONIES OF BACTERIA.

An excellent counting-plate devised by another student of the writer's is ruled in circles and sectors of circles instead of in squares. The difficulty of dealing with partial squares is thus avoided, and it is much easier to count over a specific fraction of the entire area of the Petri dish.

The inverted Petri dish may be of any thickness, and yet be kept firm against the counting-plate, and consequently always within the focus of the lens.

The method of sowing water-samples as given above is that in most common use, but a much superior manner of working is that practised first by Miquel, of Paris. He makes use of conical flasks, usually 2½ inches in diameter at the bottom, with a tubulated glass cap, ground at the

joint. The tubulation is plugged with cotton. Such flasks receive 10 c.c. each of the culture-jelly when it is first made and are kept in stock like the test-tubes. Taken to the field, they may receive, on the spot, the 1 c.c. of water, and the chances of contamination during transfer to the Petri dish, and of multiplication during the journey to the laboratory, are thereby avoided.



Miquel never permits a greater number of colonies in one flask than can be counted with the unaided eye. He accomplishes this result by first sowing one flask, as already stated; he then mixes 1 c.c. of the water with 9 c.c. of sterilized water and sows from that mixture, and afterwards mixes 1 c.c. of the water with 99 c.c. of sterilized water and sows that mixture. Of course this must be done with great care, as any error is multiplied.

Miquel does not usually count inside of two weeks, and, at times, waits even longer.

Samples for bacteriological work are far more quickly damaged by keeping than are those intended for chemical analysis; thus:

SPRING-WATER, TROY, N. Y.

November 10................	830 bacteria per c.c.
" 12................	8,128 " " "
" 13................	9,433 " " "
" 15................	12,740 " " "

Much more striking instances are given by Miquel. Thus for the Dhuis water:

	Temperature.	Bacteria per c.c.
12 noon........................	16.6° C.	57
1.30 P.M........................	19.5° "	143
3 P.M........................	20.9° "	456

	Temperature.	Bacteria per c.c.
For Vanne water:		
Immediate	17° C.	56
After 24 hours	21.2° "	32,140
Also for Vanne water:		
Immediate	15.9° "	48
After 2 hours	20.6° "	125
" 1 day	21.0° "	38,000
" 2 days	20.5° "	125,000
" 3 days	22.3° "	590,000
Deep-well water (Frankland):		
Immediate	20° "	7
After 1 day	20° "	21
" 3 days	20° "	495,000

The last instance shows that multiplication of bacteria is not to be accounted for by a simple increase of temperature.

As has been already stated, it is exceedingly important to keep water-samples at freezing temperature during transportation to the laboratory. Germs do not commonly multiply at such a temperature, but, as has been shown in France, this does not hold good for waters heavily charged with bacterial food. In one instance "sea-water, constantly maintained at 0° C., changed in bacterial contents from 150 to 520 per cubic centimetre in 24 hours."

On the other hand, great cold is not fatal to germ-life. Pictet and Yung, of Geneva, submitted a series of ordinary bacteria, furnished by Miquel, to a temperature below —100° C. during 36 hours without causing their destruction.

The number of bacteria per cubic centimetre in water-samples taken from the same source at different times will greatly vary with the season and changes in local conditions. Thus the Hudson River water sampled at the Troy intake shows the following variation in bacterial contents during the

colder half of the year; similar results for a Rensselaer County spring-water are also given:

	Hudson River.	Spring.
October	1,487	158
November	626 8,128	750
December	1,463	1,620
January	4,022	2,519
February	3,322	166
March	....	8,520
April	1,343 17,665	476

The influence of high water in the river is well shown by the difference between the early and late April samples. Surface-washing is the cause of such an increase. The effect of melting snow, and consequent surface-washing, is also shown in the March sample of spring-water.

In general, it may be said that so long as a river is fed by springs, that is, during the hot months, the bacteria tend to remain low in numbers, but with the advent of floods germ-life increases in quantity, because of the washing of the surface of the ground by heavy rainfall and melting snow. During the period when severe frost ties up all surface sources the bacteria again diminish in numbers.

Miquel gives the following averages for bacteria per cubic centimetre of Seine water taken at Ivry, and for the Vanne spring-water supply of Paris:

	Seine.	Vanne.
January	52,670	400
February	43,120	1,625
March	34,710	1,560
April	38,640	860
May	12,930	720
June	28,150	590
July	14,130	865
August	6,780	985

	Seine.	Vanne.
September	20,220	465
October	22,350	495
November	37,720	495
December	78,950	525

or

	Seine.	Vanne.
Spring	26,570	720
Summer	13,710	770
Autumn	46,340	505
Winter	43,500	1,200
Annual mean	32,530	800

The River Seine, unlike the Hudson, is not affected in the spring by the melting of great masses of northern snow.

A well-water will often show great and irregular variations in bacterial contents; thus Buchner cites the following case from Munich: *

July 1	600 bacteria per c.c.			
" 8	1,200	"	"	"
" 15	4,000	"	"	"
" 21	80	"	"	"
" 29	10,000	"	"	"
August 3	400	"	"	"

An interesting table is given in a French report, showing the variation in dissolved oxygen (parts per million) and in bacteria per cubic centimetre of Seine water during a flow of 87 miles, a large fraction of which flow is through the city of Paris:

	Dissolved Oxygen.	Bacteria.
Corbeil	12.5	14,000
Choisy-le-Roi	10.8	67,000
Auteuil	8.6	775,000
Sèvres	7.7	327,000
Suresnes	7.6	252,000

* "Das Wasser," Fischer, 36.

	Dissolved Oxygen.	Bacteria.
Asnières	7.6	401,000
Clichy	6.6	......
St. Ouen	5.8	2,040,000
St. Denis	3.8	1,562,000
Epinay	1.5	......
Argenteuil	2.1	3,576,000
Chaton	2.3	......
Bougival	2.7	......
Poissy	8.8	391,000
Treil	10.1	......
Meulan	11.7	......
Mantes	12.8	307,000

As has been said, Miquel permits only a few bacteria to enter the culture-jelly of a single flask, accomplishing this end by his system of dilution, and he then waits at least two weeks before making the count. That this method has the great advantage of permitting slowly developing colonies to grow sufficiently to be recognized, which would be otherwise lost in the crowd of liquefying bacteria, is very evident from the following figures of Miquel. Out of 1000 bacteria in water, sowed in culture-jelly, the following numbers of colonies will appear on the successive days:

1st day	20	colonies.
2d "	116	"
3d "	118	"
4th "	133	"
5th "	143	"
6th "	107	"
7th "	88	"
8th "	55	"
9th "	41	"
10th "	38	"
11th "	33	"
12th "	29	"

13th day	30 colonies.	
14th "	25	"
15th "	24	"

"The complete analysis of a water may require from several weeks to several months of constant and difficult work; I may add that, in the present state of our knowledge, it is often impossible to complete it, for the reason that several of the species of bacteria we meet with are as yet unknown." (Miquel.)

As an expression of fifteen years of experience Miquel ventures to suggest the following classification of French waters, based upon the number of bacteria per cubic centimetre:

Excessively pure	0 to 10
Very pure	10 to 100
Pure	100 to 1,000
Medium	1,000 to 10,000
Impure	10,000 to 100,000
Very impure	above 100,000

Sterilizing a water by heat is not so easy as most people imagine. Absolute sterility can be attained in about forty-five minutes by heating the water, under pressure, to 115° C.

Ordinary boiling for half an hour will destroy about 99 per cent of all bacterial life, and, fortunately, that which remains is entirely harmless. No pathogenic germs are capable of resisting such a temperature for half an hour.

Experimenting with Seine water, which contained, at the ordinary temperature of 22° C., 848 bacteria per cubic centimeter, Miquel found the following decrease in numbers of germs as the temperature was raised:

Water Maintained 15 Minutes at	Bacteria per c.c. Remaining.
43° C.	640
50° "	132
60° "	40
70° "	27.2
80° "	26.4
90° "	14.4
100° "	5.2

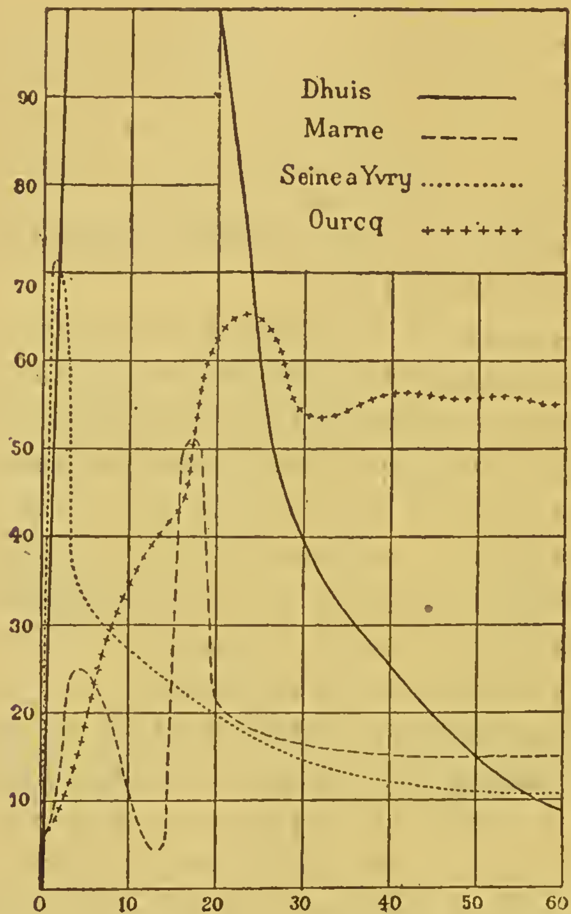
The following is a freely translated extract from Miquel's "Auto-infection of Waters":

"When samples of various waters, pure and impure, are maintained at constant temperature, say 20° C., they behave very differently in the matter of the increase of their bacterial contents. With pure waters the increase is rapid and temporary, while with impure waters it is slow and lasting. This fact appears to present great hygienic interest, for it shows that many waters are not only incapable of favoring the multiplication of certain organisms, but may be, for them, indifferent or even deadly media.

"The waters which are relatively the most nourishing to the known pathogenic organisms are the 'new' waters, that is to say, those waters which are slightly charged with bacteria, and which have never been the seat of large and sudden growths. Epidemics are more intense when the disease is transmitted by waters which are ordinarily of a high degree of bacterial purity, by a 'new' water, for instance, which permits the disease-bacilli to multiply in great numbers without difficulty. In the impure waters, such as have supported many generations of various bacteria, there have been secreted, during the existence of these organisms, certain toxins which oppose the further multiplication of germs, if they do not rapidly kill them."

Whatever may be the exact nature of the toxins referred to, they seem to be readily volatile. If water be slowly

distilled, in specially constructed apparatus, at 30° to 35° C., such a distillate will not support bacterial life. Thus, when



SHOWING RELATIVE RAPIDITY OF BACTERIAL GROWTH IN PURE (DHUIS) AND IMPURE (OURCQ) WATERS

inoculated with germs from the dust in 1650 litres of laboratory air, the counts per cubic centimetre were as follows:

Immediate.....	75	bacteria per c.c.
After 6 days..................	7	" " "
" 16 "	1.5	" " "
" 27 "	1.5	" " "

In contrast with this note the rapid increase following the

addition of the dust from 20 litres of air to river-water previously sterilized in the ordinary manner.

Immediate................	6.5	bacteria per c.c.
After 7 days.............	750,000	" " "
" 10 "	900,000	" " "
" 31 "	1,675,000	" " "
" 90 "	62,500	" " "
" 119 "	86,750	" " "
" 272 "	48,000	" " "

Note also the decrease in germ-life as the bacterial toxins accumulate.

Cramer's observations upon water from Lake Zurich also show the same decline in bacterial life through long keeping of samples:

Immediate..................	143	bacteria per c.c.
After 1 day...............	12,457	" " "
" 3 days..............	328,543	" " "
" 8 "	233,452	" " "
" 17 "	17,436	" " "
" 70 "	2,500	" " "

For the enumeration of organisms, not bacteria, in water Mr. Geo. W. Rafter proposes the following improvement upon the method employed by Prof. Sedgwick: He filters a measured quantity (500 c.c. or 1000 c.c.) of the water through a small plug of sand held in the lower portion of a funnel-stem, and then rinses the sand, and its collection, into a test-tube. After settling of the sand the liquid is decanted into another test-tube, and diluted to a known volume. After stirring 1 c.c. of the liquid is transferred to a special counting cell (50 × 20 × 1 millimetre), which it just fills. A cover-glass is floated upon the top, and the cell bottom is ruled into 1000 squares one millimetre on a side. Counting is thus rendered easy.

CHAPTER XII.

QUANTITY OF PER CAPITA DAILY SUPPLY.

THE following table is condensed from a very complete one, issued recently as a supplement to the *Water and Gas Review*:

City.	Population.	Total Cost of Furnishing One Million Gallons of Water.	Daily Consumption per Capita, Gallons.	Rate Charged per Thousand Gallons, Cents.
New York, N. Y.	1,900,000	about $50	92	12½
Chicago, Ill.	1,800,000	....	131	8 to 10
Philadelphia, Pa.	1,200,000	....	143	4
Brooklyn, N. Y.	1,000,000	about $100	100	7½ to 11⅝
St. Louis, Mo.	574,569	....	75	10 to 30
Boston, Mass.	558,400	....	92	15 to 17½
Baltimore, Md.	500,000	....	....	5½
Pittsburg (south side).	366,000	....	220	4.8
Buffalo, N. Y.	300,000	....	217	2½ to 6
Cincinnati, O.	300,000	....	124	8½ to 16½
Detroit, Mich.	257,000	$32	140	3⅛ to 6⅝
Milwaukee, Wis.	250,000	....	105	....
Washington, D. C.	230,000	....	177	....
Louisville, Ky.	200,000	about $40	80	6 to 15
Toronto, Ont.	188,000	....	100	12½
Omaha, Neb.	160,000	....	....	10 to 35
St. Paul, Minn.	150,000	....	....	10 to 20
Providence, R. I.	150,000	....	60	20
Rochester, N. Y.	145,700	$160	48	14
Indianapolis, Ind.	115,000	....	74	5 to 25
Allegheny, Pa.	105,000	....	247	....
Syracuse, N. Y.	105,000	$26.35	....	6 to 25
Atlanta, Ga.	106,000	$70.89	164	12½
Toledo, O.	100,000	....	70	3 to 10
Albany, N. Y.	98,000	....	162	....
Grand Rapids, Mich.	90,000	$30.70	88	3½ to 15
Richmond, Va.	90,000	....	151	7 to 15
New Haven, Conn.	90,000	....	130	7½ to 30
Fall River, Mass.	87,773	....	28	....
Lowell, Mass.	87,000	....	75	....
Quebec, P. Q.	80,000	$44.00	125	....
Dayton, O.	76,000	$50.00	53	8
Des Moines, Iowa.	70,000	$80 to $100	43	20 to 40
Los Angeles, Cal.	70,000	$30.00	200	20
Troy, N. Y.	65,000	....	....	5

City.	Population.	Total Cost of Furnishing One Million Gallons of Water.	Daily Consumption per Capita, Gallons.	Rate Charged per Thousand Gallons, Cents.
Charleston, S. C.	64,000	...	22	20 to 50
Hartford, Conn.	62,000	...	125	7½ to 30
Saginaw, Mich.	60,000	$13.25	100	6 to 11
New Bedford, Mass.	55,000	$43.59	99	2½ to 15
Manchester, N. H.	51,000	$67.00	50	20
Birmingham, Ala.	50,000	...	160	8 to 30
Covington, Ky.	50,000	$120.00	62	8 to 18
Utica, N. Y.	50,000	...	...	7½ to 30
Springfield, Mass.	49,299	...	87	30
Harrisburg, Pa.	45,000	...	130	2½ to 10
Augusta, Ga.	40,000	...	106	10
Sioux City, Iowa.	40,000	$45.00	43	10 to 25
Holyoke, Mass.	40,000	...	77	5 to 15
Binghamton, N. Y.	38,000	...	...	5 to 25

To these data may be added the following figures, showing daily consumption in U. S. gallons per capita:

Paris (spring-water supply only)	20
Hamburg	26
London (for all uses*)	44
" (for domestic use)	39

The average daily per capita supply for the cities and towns of New Jersey † for 1893 was 99 gallons. (See table top of page 440.)

The nine large conduits of Rome at the time of Nero delivered 173,000,000 gallons daily. Afterwards the increased supply furnished 312,000,000 gallons daily, or over 300 gallons per capita per day.‡

Upon glancing over such data as have been given for cities of the United States, and bearing in mind how often

* The entire daily supply for London during August, 1893, averaged 245,000,000 U. S. gallons.

† Report of State Geologist.

‡ 52d Congress, Sen. Doc. 41, part 1, page 431. For Forbes's estimate see page 5.

USE OF WATER IN SOME GERMAN CITIES (GALLONS PER CAPITA DAILY).

(After Brackett.)

Place.	Population.	Consumption.	Place.	Population.	Consumption.
Altona..........	156,500	26.07	Hanover.........	189,976	18.40
Barmen..........	118,500	33.59	Halle............	120,000	21.94
Basel............	74,500	34.78	Karlsruhe	74,200	28.14
Berlin...........	1,606,424	16.37	Kiel.............	72,000	20.18
Bonn............	52,000	24.94	Königsberg......	162,000	16.87
Breslau..........	335,000	21.71	Magdeburg	198,000	25.24
Chemnitz.......	139,374	11.50	Munich..........	298,000	34.00
Cologne.........	255,000	45.22	Nuremburg... ...	145,000	17.41
Crefeld..........	105,712	18.52	Posen...........	70,000	13.33
Danzig..........	107,085	26.70	Stettin...........	118,000	31.54
Dresden.........	280,200	21.54	Stuttgart.........	139,200	21.34
Dusseldorf.......	155,900	22.10	Wiesbaden.......	66,000	20.74
Elberfeld........	137,000	29.92	Wurzburg........	61,032	35.50
Frankfort........	186,000	36.26	Zurich...........	96,650	56.71
Freiburg, B......	48,200	41.46			
Hamburg.... ...	583,700	58.00	Average.....	....	27.69

the water furnished our towns is inferior in character, one is impressed with the thought that we Americans are much more concerned about the quantity of the supply than about its quality.

There is no question but that our allowance is unreasonably large. Fifty gallons is considered a generous amount per individual in Europe, but it would be considered quite a small allowance here in America.

If we had but an increased cleanliness to show for our great use of water, there would be a measure of compensation for the additional cost, but the writer confesses to an inability to detect wherein our American cities exceed the European capitals in this particular.

Mr. D. Brackett makes the following analysis of the daily uses of water:

"The quantity needed for domestic use is not more than 30 gallons per inhabitant, and in communities where the number of water-fixtures is small in proportion to the popu-

CONSUMPTION PER CAPITA IN BOSTON, BROOKLINE, NEWTON, FALL RIVER, WORCESTER, YONKERS, AND LONDON, AS DETERMINED BY METER MEASUREMENT.

City or Town.	Number of Houses.	Number of Families.	Number of Persons.	Consumption, Gallons per Family.	Consumption, Gallons per Capita.	Remarks.
Boston.........	31	402	1,461	221	59	Highest cost apartment-houses in the city.
Boston.........	46	628	2,524	185	46	First-class apartment-houses.
Boston.........	223	2,204	8,432	123	32	Moderate class apartment houses.
Boston.	39	413	1,844	80	16.6	Poorest class apartment-houses.
Boston.	339	3,647	14,261	139	35.6	Average of all apartment-houses supplied by meter.
Boston.	40	......	1,699	......	46.1	Boarding-houses.
Brookline	...	828	4,140	221.5	44.3	Average of all dwellings supplied by meter.
Newton.... ...	490	490	2,450	132.5	26.5	All houses supplied with modern plumbing.
Newton........	.. .	619	3,005	......	6.6	These families have but one faucet each.
Newton.... .	...	278	1,390	34.5	6.9	These families have but one faucet each.
Fall River......	28	34	170	127.5	25.5	The most expensive houses in the city.
Fall River......	64	148	740	42.0	8.4	Average class of houses, generally having bath and water-closet.
Fall River......	....	......	70,000	......	12.3	Total domestic consumption.
Worcester......	....	20,514	90,942	......	16.8	Whole domestic consumption.
Worcester......	...	81	327	80.2	19.9	Woodland street, best class of houses.
Worcester.. ...	...	37	187	118.1	23.4	Cedar street, best class of houses.
Worcester.. ...	....	93	447	95.0	19.8	Elm street, houses of moderate cost.
Worcester......	....	245	1,104	55.1	12.2	Southbridge street, cheaper houses.
Worcester......	....	229	809	55.0	15.6	Austin street, cheaper houses.
Yonkers, N. Y.	....	......	31,000	......	21.4	
London, Eng..	1169	......	8,183	......	25.5	Houses renting from $250 to $600; each have bath and two water-closets.
London, Eng..	727	... ..	5,089	.....	18.6	Middle class; average rental, $200.

lation supplied a smaller quantity will answer all requirements. For business, mechanical and manufacturing uses, the amount per capita will differ very largely in different cities, and for various reasons. It is not probable, however, that the actual requirement exceeds 40 gallons per capita in any of our large cities.

"The quantity needed for public use is not more than 5 gallons, making a total of 75 gallons as the maximum quantity needed for actual use, without any allowance for waste." *

The quantity of water delivered to our American cities is not only great, but is distinctly increasing, as is shown by the statistics collected by Brackett:

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* *Jour. Am. Soc. C. E.* XXXIV. 185.

DAILY AVERAGE CONSUMPTION OF WATER IN GALLONS PER

	Years.	Boston, Cochituate Works.	Boston, Mystic Works.	Chicago.	Philadelphia	Brooklyn.	St. Louis.	Cincinnati.	Cleveland.	Detroit.
Population.	1850	139,800	......	29,963	121,376	96,838	77,860	115,435	17,034	21.019
	1860	177,900	......	112,172	565,529	266,661	160,773	161,044	43,417	45,619
	1870	225,100	87,071	298,997	674,022	396,099	310,864	216,039	92,829	79,577
	1880	306,000	107,700	503,185	847.170	566,663	350,518	255,139	160,146	116,340
	1890	410,130	117,500	1,099,850	1,046,964	806,343	451,770	296,908	261,353	205,876
Daily Average Consumption.	1850	42	......	......	......	......	......	20	......	......
	1855	64	......	......	......	......	......	25	......	44
	1860	97	......	43	36	......	......	30	14	52
	1865	66	27	42	50	29	......	29	22	55
	1870	66	44	73	55	47	......	48	31	64
	1871	60	56	72	55	47	......	53	36	76
	1872	63	70	74	54	53	45	54	40	88
	1873	72	77	88	56	59	51	50	43	98
	1874	72	73	96	58	54	55	55	45	97
	1875	69	86	100	69	59	61	60	44	120
	1876	71	80	103	......	57	62	68	49	111
	1877	72	75	......	58	59	66	64	56	111
	1878	80	76	123	64	58	67	66	51	110
	1879	87	88	......	66	60	72	68	63	125
	1880	87	87	112	68	54	72	76	65	130
	1881	94	80	......	71	56	76	87	77	145
	1882	95	73	110	76	58	76	69	68	132
	1883	97	74	......	76	58	75	66	76	146
	1884	73	65	114	74	61	63	74	83	159
	1885	73	68	116	72	64	67	64	93	176
	1886	74	72	118	80	65	73	74	91	176
	1887	80	72	120	89	65	73	88	96	197
	1888	87	75	119	100	67	74	99	95	204
	1889	81	69	123	110	67	73	99	99	172
	1890	83	71	127	132	68	78	115	106	155
	1891	90	75	135	140	70	83	138	111	144
	1892	96	79	134	143	79	89	123	118	140
	1893	107	86	147	150	86	95	124	130	148
	1894	101	89	......	......	......	......	......	......	144

The simple, useless waste of water in our cities is something enormous. In Chicago, Cleveland, Philadelphia, and Detroit the probable waste is fixed at about 50 per cent, while in Buffalo the enormous figure of 70 per cent is given by the city engineer. The waste for New York City is given as "at least 40 per cent" by the *Water and Gas Review.*

That the great bulk of this waste could be saved by meter measurement is an already demonstrated fact, and the fixing of a minimum daily allowance of water, for which the consumer would have to pay, whether he used it or not, would remove the objections that might be raised to meters upon sanitary grounds. The author has corresponded with city health officers in various parts of the country, with a

CAPITA PER DAY IN VARIOUS CITIES IN THE UNITED STATES.

Mil-wau-kee.	Louis-ville.	Provi-dence.	Lowell.	Fall River.	Cam-bridge.	Lynn.	New Bed-ford.	Salem.	Year.	
20,061	43,194	41,513	33,383	11,524	15,215	14,257	16,443	20,264	1850	Population.
45,246	68,033	50,666	36,827	14,026	26,060	19,083	22,300	22,252	1860	
71,440	100,753	68,904	40,928	26,766	39,634	29,233	21,320	24,117	1870	
115,587	123,758	104,857	59,475	48,961	52,669	38,274	26,485	27,563	1880	
204,468	161,129	132,146	77,696	74,308	70,028	55,727	40,733	30,801	1890	
...	...	...	...	...	...	...	...	...	1850	Daily Average Consumption.
...	...	...	...	...	...	...	...	...	1855	
...	...	...	...	...	...	...	...	...	1860	
...	18	...	...	...	...	...	...	...	1865	
...	23	...	...	...	44	...	...	31	1870	
...	21	...	...	...	43	...	...	38	1871	
...	22	...	...	...	38	...	...	45	1872	
...	22	...	...	...	48	41	...	55	1873	
...	24	...	...	12	50	42	...	51	1874	
29	24	...	24	18	57	40	...	...	1875	
45	27	...	29	25	51	32	...	59	1876	
69	29	24	30	26	53	32	...	58	1877	
85	30	26	32	25	45	32	...	53	1878	
96	33	30	35	27	47	34	...	55	1879	
106	42	34	38	28	46	32	...	55	1880	
109	56	35	40	30	46	32	86	59	1881	
114	47	33	43	36	45	37	82	63	1882	
108	52	37	46	31	47	36	78	61	1883	
101	56	34	48	26	46	39	72	60	1884	
105	62	37	56	26	51	42	85	62	1885	
110	65	37	59	27	56	44	86	64	1886	
117	64	37	62	25	60	48	85	77	1887	
105	62	40	69	28	63	45	88	71	1888	
116	67	41	62	27	62	43	89	68	1889	
114	71	46	69	28	65	45	98	69	1890	
112	78	48	74	30	67	49	92	87	1891	
101	81	57	73	27	71	53	88	81	1892	
108	75	63	79	27	80	54	91	66	1893	
...	...	...	75	...	70	...	...	...	1894	

view of determining what, if any, is the effect of the meter system upon public health, arising from an attempt on the part of the poorer classes to economize in the use of water. The reply from Providence, R. I., is quite typical: "I do not find that it diminishes the proper use of water in the slightest degree. Its only tendency is to diminish waste. There is in my opinion no objection, from a sanitary point of view, to the use of meters."

How great the useless waste of water may be is well shown by Mr. F. Crosby,* who has prepared a somewhat lengthy table of daily per capita supplies before and after

* *Jour. Am. Water-works Asso.*, 1895, page 90.

such waste was stopped. Taking an average of twenty of the numerous cases quoted, the per capita figures stand:

Before repairs were made..............	1572 gallons
After " " "	281 "

The experience of Mr. Dexter Brackett leads him to be "of the opinion that it is not practicable to reduce the waste below 15 gallons per capita in our large cities, and that it cannot be maintained at that figure except by the universal use of water-meters, aided by Deacon meters or some similar device for detecting leaks in the street mains. In cities where water-meters are not generally used the quantity wasted will be from 20 to 100 gallons per capita, as the inspection of mains and house-fixtures is more or less rigid."

"The following-named cities are fair illustrations as to prevention of waste as shown by the use or absence of a meter system:

"Atlanta, 89.6 per cent, metered, 36 gallons per capita.

"Fall River, 74.6 per cent, metered, 29 gallons per capita.

"Allegheny City, no meters, 238 gallons per capita.

"Buffalo, $\frac{2}{10}$ per cent metered, 186 gallons per capita.

"Richmond, 1.4 per cent metered, 167 gallons per capita.

"Detroit, 2.1 per cent metered, 161 gallons per capita.

"Halifax, with one half the population of Fall River, has three times the per capita consumption." *

A spirit of prophecy must certainly enter the engineer who would accurately determine the future population of a city in order to provide sufficiently for its water-supply.

In a paper read before Section I, American Association for the Advancement of Science, at Springfield, Mass.,

* *Water and Gas Review.*

September 3, 1895, Mr. E. L. Corthell dealt exhaustively with the growth of population of great cities and graphically illustrated the several densities and curves of increase.

"Recapitulating the statements in regard to ratio of increase at present in the several cities noted, the following summary is given:

PRESENT PERCENTAGE OF INCREASE PER DEDADE.

London	10.4
Greater London	18.0
New York	33.3
Paris	10.0
" average last three decades	12.7
Chicago	106.5
Berlin	37.0
Philadelphia	25.0
St. Petersburg	15.0

"Even with the problematic conditions disturbing the future, there is sufficient ground on which to rest a prediction of population, which the author has the temerity to make, as follows:

City.	Est. pop. in 1900.	Est. pop. in 1910.	Est. pop. in 1920.
Greater London	6,496,000	7,470,400	8,516,256
London	4,599,800	4,967,784	5,315,528
New York	3,900,000	4,953,000	6,191,250
Paris	2,697,300	2,967,030	3,234,063
Berlin	2,101,400	2,731,820	3,496,729
Chicago	2,400,000	4,560,000	8,208,000
Philadelphia	1,414,500	1,697,400	2,002,932
St. Petersburg	1,185,600	1,339,728	1,500,495

As supplementary to what is found on page 438 relating to rates charged for water the following is given as applying to eleven cities that have adopted the general meter system: *

* *Water and Gas Review.*

	Rate.	Per Galls.	Minimum.
San Francisco, Cal...	$21\frac{1}{8}$ to 40c.	1000	$19.00
Providence, R. I.....	15 " 20	"	10.00
Fall River, Mass.....	10 " 28	"	16.00
Hoboken, N. J.......	$15\frac{2}{8}$ " $23\frac{1}{3}$	"	13.00
Yonkers, N. Y.......	$5\frac{1}{3}$ " $26\frac{4}{5}$	"	13.00
Pawtucket, R. I......	6 " 30	"	10.00
Newton, Mass........	12 " 35	"	10.00
Woonsocket, R. I....	10 " 30	"	10.00
Bayonne, N. Y.......	$13\frac{1}{2}$ " $23\frac{1}{3}$	"	.....
Fitchburg, Mass.....	5 " 35	"	.....
Madison, Wis........	$6\frac{2}{8}$ " $26\frac{2}{8}$	"	5.00

A city ordinance of Brooklyn, N. Y., reads as follows :

"All water used for manufacturing purposes shall be charged for at the rate of one cent per one hundred gallons, or seven and one half cents per one hundred cubic feet, meter measurement. All water furnished and used for other purposes shall be charged and paid for at a rate of one and one half cents per hundred gallons, or eleven and one quarter cents per one hundred cubic feet, meter measurement, provided, however, that in cases where an annual supply of water for a given purpose exceeds in cost the sum of one thousand dollars, meter measurement, such supply of water shall be furnished and paid for at the rate charged for manufacturing purposes."

In Paris the spring-water supply is charged for at the rate of 35 centimes (7 cents) per cubic metre (264 U. S. gallons), with special reduction for the small houses of working-men.

CHAPTER XIII.

ACTION OF WATER UPON METALS: TANKS, PIPES, CONDUITS, BOILERS, ETC.

Lead.—Max Müller finds that the action of soft water on lead depends upon the relative amounts of oxygen and carbon dioxide present in solution. Distilled water, free from carbon dioxide, but containing oxygen, hardly acts upon lead, and water containing carbon dioxide, but no oxygen, is also without action; yet waters containing a fixed amount of dissolved oxygen, and varying amounts of carbon dioxide, were found to act upon lead with an energy which increased directly as the amount of carbon dioxide present, up to a certain limit, after passing which the addition of more carbon dioxide diminished the action upon the lead and finally stopped it altogether.*

A. H. Allen finds by experiment that distilled water, acting overnight on bright lead, will contain lead carbonate an amount equal to 5.83 grains per U. S. gallon.†

Sulphuric acid, even in very small quantity, will, contrary to former opinion, increase the action of ordinary (not distilled) water on lead. Allen believes ‡ the leading cause of the action of potable waters on lead to be the presence of a trace of some free acid.§

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* *J. Chem. Soc.* LIV. 225. † 100 parts per million.

‡ *Chem. News*, XLVI. 145.

§ Lead water-service pipes at Kingston, Mass., have been declared dangerous by the State Board of Health, according to reports. It is stated that the water contains a sufficient amount of acid to liberate the lead from the pipes, thus charging the water with this poison.

Mr. Scattery, of England, has made some investigations relative to the influence of peaty material in causing an acid reaction in water and a consequent action upon lead. The plumbo-solvency of a troublesome water of this class in use at Wakefield, England, has been entirely removed by the use of carbonate of soda.

A paper by Dr. Thompson before the British Medical Association in 1890 stated that Sheffield had a double supply of water: a high-level supply gathered from a damp peaty ground and delivered in an open conduit; and a second one, uncontaminated with vegetable material, and which flowed in a closed conduit. The former of these waters acted on lead pipe, and the latter did not. Many persons had died in Yorkshire from lead poisoning.*

The medical officer of health for Eccleshill, England, reports that the water-supply of the district contains lead to the average quantity of $\frac{1}{6}$ grain per imperial gallon.† Iron pipe is being substituted for all new services in the district.‡

This entire question of the action of moorland and peaty waters upon lead is being investigated by the London Local Government Board, England.

That all peaty waters act on lead must not be inferred, as some very brown ones, notably from New Jersey, are without such action.

In a general way, it may be said that soft waters attack, and hard waters protect, lead, but this rule is not without numerous exceptions, and one interesting exception is the fact that permanently hard water tends to attack the metal rather than to protect it. Waters of acid reaction take lead into solution, while those of neutral or alkaline character hold the basic hydrate or basic carbonate in suspension. As the latter class of waters often attack lead quite vigorously,

* Report Surg. Gen. U. S. Navy, 1890.

† 2.38 parts per million.

‡ *Chem. News*, LXX. 222.

the quantity of lead actually imbibed with an unfiltered water of this class may be considerably larger than in the case of a water where the lead is in solution.

There is often some question as to what produces the acidity of a particular water, but one eminent investigator believes that nitric acid is very commonly the cause. Certain it is that nitrates are ordinarily present in waters which attack lead.*

A very marked difference commonly exists between the action of the same water upon new, bright lead, and upon that which is dull from exposure, i.e., "old lead."

Thus the writer found the following amounts of the metal (partly dissolved and partly suspended) in city rain-water which had been stored three and a half months in contact with lead-surfaces of the above description:

Old lead................	3.65 parts per million			
New lead...............	58.10	"	"	"

The important lesson derived from this is that lead-lined tanks for storage of rain-water, such are so often seen in the

* Instances are on record of lead pipes having been in use during many years without having been acted upon by the water passing through them. Thus Fischer cites a case where the pipes had served over 200 years without action. An interior incrustation on a lead pipe which had been in use for conveying water at Andernach during a period of 300 years, was found to consist of:

PbO......................	73.962	P_2O_5......................	8.446
BiO_3......................	0.453	CO_2......................	1.110
CdO......................	0.120	Cl......................	1.254
CuO......................	0.323	Organic matter..............	0.388
Fe_2O_3......................	1.552	SiO_2 and clay..............	4.399
Al_2O_3......................	1.035	Water......................	6.141
CaO......................	1.095		
MgO......................	0.283		100.561

The organic matter was said to have been caused by eels which had been formerly employed to clear the pipe from material which had clogged it. (*J. Chem. Soc.* XXXVIII. 198.)

country, may grossly contaminate the water, especially while new, by diffusing throughout their contents the solid lead compounds formed by the action of the water. This form of contamination may be much greater than that arising from the lead actually in solution; but either form is bad, and if lead cisterns or storage-tanks be deemed necessary they should always be carefully painted on the inside with a good carbon (non-metallic) paint, and should be frequently inspected.*

In this connection may be mentioned the danger of having a suction-pipe of unprotected lead leading to the bottom of the domestic well or the cement-lined cistern.

As already said, all waters do not act upon lead, and some very quickly form upon the metal a permanent protective coating; but, in order to decide in which class to place any given water, it is much better to settle the question by direct experiment, such as permitting two samples of the water to stand in contact with bright and with dull metal, afterwards estimating the lead in each sample by the method already given, rather than to theorize upon the basis of the composition of the water.

Carbonate of calcium is very efficient in protecting lead from attack.

Crookes, Odling, and Tidy have shown also the great protecting power of calcium silicate, and their belief is that water becomes lead-proof when the contained silica amounts to about 7 parts per million.†

Where circumstances permit, an excellent method of checking the lead-dissolving powers of a soft water for city

* It is thought that as little as $\frac{1}{40}$ grain of lead to the gallon has caused sickness, but $\frac{1}{10}$ grain is usually considered as the outside permissible limit." (Taylor on Poisons.)

† *J. Soc. Chem. Ind.* VII. 15.

supply is to admit to the reservoir or mains a suitable quantity of pure, temporarily hard spring-water. The amount of such spring-water required would depend upon its composition, but would be probably very small.

Zinc.—Galvanized-iron pipe is now so largely employed for carrying water that the possibility of the zinc coating being attacked has become an important question.

Haines reports the presence of large quantities of zinc in water from a deep rock-drilled well near Philadelphia.* The outer casing, as well as the inner tube, are of galvanized iron. The water contained:

Free ammonia	4.73
Albuminoid ammonia	.08
Chlorine	8
Nitrates	trace
Zinc	53.7
Total residue	155

Note that the nitrates probably present originally in the water have been reduced by the "zinc-iron couple" to ammonia.

A similar case of reduction is given by Heaton.†

The spring-water forming the public supply of Cwmfelin is carrried through half a mile of galvanized-iron pipe. The influence of such carriage upon the character of the water is shown by the analyses here quoted:

	At Spring.	At Delivery.
Free ammonia	none	.114
Nitrogen as nitrate	.8	none
Total residue	154.3	270
Zinc carbonate	none	91.6

An examination made by the writer of a rain-water which

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* *J. Fk. Inst.*, November, 1890.

† *Chem. News*, XLIX. 85.

had been stored in a galvanized-iron tank during four and a half months showed 20.9 parts metallic zinc per million of water.

As in the case of lead, it is better to experimentally determine the action of a given water upon zinc, rather than to attempt to predict the same from a knowledge of the composition of the water.

Unlike lead, zinc is not a cumulative poison, therefore the presence of the metal in very small quantities is not so objectionable. There are not a few authorities who claim that zinc poisoning, through the use of water, has not been proven, although P. F. Frankland reports such a case arising from the use of water from a shallow, sewage-polluted well. Waters from such wells were long ago shown to act quickly upon zinc.*

In the *Analyst*, IV. 51, is a report of an analysis of the spring-water supply of Tuttendorf, Germany. The zinc present corresponds to .007 part of the oxide per million, yet this water has been in use a century.

With reference to the action upon health of the Cwmfelin supply, spoken of above, no report is forthcoming.

The great insolubility of those compounds of zinc commonly formed by the action of water upon the metal constitutes a material safeguard in its use.

Dr. Boardman† believes that oxide of zinc, as it occurs in drinking-water, is absolutely harmless. He says the same of the carbonate. As to salts in solution, he adds: "Admitting, then, that water which has been stored in reservoirs or drawn through pipes of galvanized iron always contains zinc in solution, in the form of one or more of its salts, the innocuity of those salts, in the quantities in which they occur,

* Rivers Pollution Commission, 6th Report.

† Report Mass. Board of Health, 1874.

is attested by the experience and experiments of distinguished observers."

He further says: "At least with water fit for drinking purposes in other respects the contained zinc salts in solution do not exert any deleterious effects upon the human system. Even if all the zinc in solution were in the form of chloride, the most active poison of the zinc salts, the amount would still be insufficient to endanger health." *

However willing most of us may be to agree with the doctor in his first remarks, it would be doubtful policy to follow him to the extent of this final statement.

There is reason to believe that certain waters can furnish dangerous quantities of zinc, and the use of galvanized iron for transmission of a water-supply should not be decided upon until chemical examination has shown the water in question to be without material action upon the zinc coating.

Iron.—When present, this metal is ordinarily in the water before it enters the distributing-mains, and is not a result of action upon the iron pipes. Chalybeate waters hold the iron in solution as a carbonate, and inasmuch as $\frac{1}{4}$ grain of the metal per gallon will give a distinct taste, it would be difficult to make such a supply popular with the public, even were the water not unsuited to a variety of uses, such as dyeing and washing.

Such action as takes place upon the iron mains does not cause deterioration of the water carried in them, except in instances where the pipes lie empty a portion of the time, as when a surface pipe is drained in winter to avoid freezing. Iron corrodes very rapidly under such circumstances, and,

* The chloride is perhaps the most poisonous of the ordinary salts of zinc; and yet, although small doses have killed, very large doses have been recovered from. In one instance, known to the writer, a glassful of the solution was taken in mistake for Hunyadi water. Vomiting immediately ensued and very serious illness followed, but the final recovery was complete.

when the water is turned on again in the spring, the iron oxide stains it for a considerable time.

Cast iron pipes corrode more quickly in water containing an admixture of salt; this is seen in the street mains laid near the New York docks. "The life of a pipe is very short in such locality, and sixteen to twenty-five years is probably the limit of service." *

The following abstract from Trautwine deals with the special action of sea-water upon iron:

"Genl. Pasley examined cannon and other metal from the wreck of the Edgar, which had been sunk in sea-water for one hundred and thirty-three years, and reports that 'the cast iron had generally become quite soft, and in some cases resembled plumbago. Some of the shot, when exposed to the air, became hot, and burst into many pieces. The wrought iron was not so much injured, except when in contact with copper or brass gun-metal. Neither of these last was much affected, except when in contact with iron."

H. M. Howe gives the following in his "Metallurgy of Steel":

LOSS OF WEIGHT IN POUNDS PER SQUARE FOOT OF EXPOSED SURFACE PER ANNUM.

	Exposed to the Weather Inland.		Immersed in		Average.
	Canada.	New York State.	Fresh Water.	Sewage.	
Wrought iron, black—i.e., unprotected	.0013	.0226	.1370	.1690	.0825
Cast iron, black—i.e., unprotected	.0063	.0120	.1483	.2724	.1066

There is a tendency with most waters to form what are known as tubercles upon the inside of iron water-mains.

* *Jour. Am. Water-works Asso.* XII. 27.

These are irregular projections, representing gradual accumulation, and consist largely of hydrated oxide of iron, at times mixed with some carbonate. The evil resulting from their presence is the material lessening of the delivering capacity of the main.

In a paper by Mr. James Duane, in the transactions of the Am. Soc. C. E. for January, 1893, the deductions are as follows:

"(1) An uncoated main conveying water of the general chemical composition of the Croton will become badly tuberculated in seven years, or probably much less.

"(2) That having reached a certain stage no further deterioration takes place.

"(3) That in a 48-inch main (uncoated) the discharging capacity is reduced about 30 per cent (by tuberculation); or, to put it another way, tar coating at present prices is worth about $20,000 per mile.

"(4) That a properly applied tar coating is an absolute protection against tuberculation, a 48-inch main after eleven years' service showing as high a coefficient as when first brought into use."

Exception was taken during the discussion of this paper to the statements concerning the arresting of the tuberculation process, for which the reader is referred to the original article.* The "tar coating" is thus described in the *Engineering News*, September 26, 1895:

"Dr. Angus Smith patented his process in England about

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* A piece of 6-inch cast-iron water-pipe, laid in 1822, was recently examined by Mr. John C. Trautwine, Jr., chief engineer of the Water Bureau of Philadelphia. He found the thickness of the iron about the same as when laid, the outside showing little effect from rust, though the pipe was not dipped in any preservative compound before laying. The inside, however, was incrusted with a compound of oxide of iron and graphite, which occupied about one fifth of the total cross-section of the pipe. Practically no incrustation was found in a pipe laid in 1874; but this pipe had been coated inside and out before laying.

1850, and it was applied to the first coated pipes used in the United States, imported from Glasgow in 1858. His 'coal-pitch varnish' is distilled from coal-tar until the naphtha is entirely removed and the material deodorized He recommends the addition to this of from 5 to 6 per cent of linseed-oil. To coat the pipes, the pitch is heated in a suitable bath or tank to a temperature of about 300° F., and into this bath the pipes are immersed and allowed to remain until they, too, attain a temperature of 300° F. Mr. J. T. Fanning, in his "Water-supply Engineering," states that a more satisfactory method is to heat the pipes in an oven to about 310° and then immerse them in the pitch-bath, which is maintained at a temperature of not less than 210°. The linseed-oil has a tendency to float and separate from the pitch at high temperatures. An oil distilled from coal-tar is now more generally used. The pipes should be free from rust and absolutely clean before treatment."

Mr. de Varona's recent report upon additional water-supply for the city of Brooklyn sets forth the excellent results observed from the use of a pipe-coating of which the main constituents are Trinidad asphalt and linseed-oil in certain proportions. The pipes, previously heated, are dipped in the coating-tank, whence they are taken out and baked in a vertical position during twelve or fourteen hours.

As replacing the old Bower-Barff process, by which a coating of magnetic oxide is deposited upon the hot metal, through the agency of superheated steam, according to the equation

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2,$$

there has been introduced the Bertrand method, by which the same oxide is applied, but more after the manner of an enamel, and without that tendency to crack off which has always been an objection to the Bowers-Barff coating for water-pipe.

Boilers may be affected by water in two ways, namely, through corrosive action of the water itself, or, indirectly, through the secondary evils resulting from scale formation.

Any free acid is objectionable in a boiler-water, even carbonic acid, if the quantity be large. Sulphuric acid, so commonly present in mine-water from decomposition of iron pyrites, is highly objectionable:

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4.$$

Magnesium chloride is especially to be avoided for boiler uses, because the salt decomposes at the high temperature attained, with production of free hydrochloric acid.

This acid, being readily carried over in the steam, the damage that it works is not confined to the boiler alone.

The liberation of free fatty acid by the steam acting under pressure* upon lubricating-oils is another common cause of corrosion.

It being known that ammonium chloride will prevent the decomposition of magnesium chloride, during evaporation, by forming therewith a stable double chloride, A. H. Allen suggests that the sodium chloride of sea-water acts in a similar way for the protection of marine boilers from the magnesium chloride found in sea-water. His remedy for stationary boilers compelled to use magnesium waters would be to add common salt to the feed-water.†

In view of the bad effects of magnesium chloride upon boilers, he further contends that it should appear in the analysis to the fullest extent compatible with the total amounts of chlorine and magnesium.

Water strongly alkaline with sodium salts, as is found in certain sections of the West, is also corrosive, for instance,

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* The widely known "Tilghman patent" is an instance of such action.

† *J. Soc. Chem. Ind.* VII. 800.

such a water as that from Bitter Creek, Wyoming, which contains:

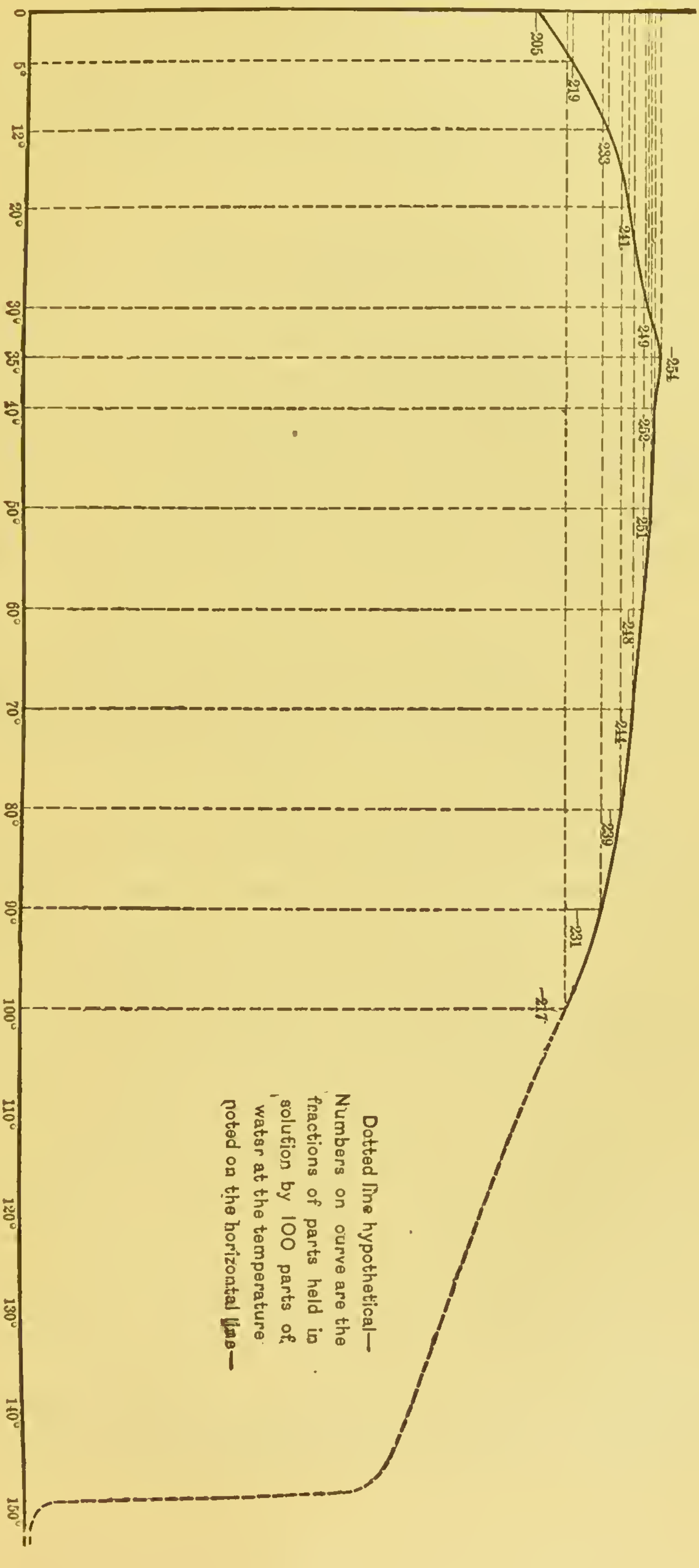
	Per Million.
Calcium carbonate	13.1
Silica (clay)	3.9
Calcium sulphate	trace
Sodium sulphate	431.0
Sodium carbonate	843.1
Sodium chloride	96.3
Silica (in solution)	8.6

Such a water could be purified for boiler purposes by the use of barium chloride; but another, and possibly cheaper, method under the circumstances is that employed by Mr. A. Pennell. He writes to the author: "Calcium sulphate is added, which forms sodium sulphate and precipitates calcium carbonate. A further dose of gypsum is then added, and the water is heated to 200° F., whereupon glauberite ($Na_2SO_4 . CaSO_4$) precipitates as semi-transparent crystals. All does not precipitate at this temperature, but the rest falls at boiler temperature and is blown off at intervals."

Boiler-scale may be classified as of two general kinds; first, that which is friable and mud-forming, such as is caused by the employment of temporarily hard water; and, second, a hard, compact, and adherent form, arising from the use of water of permanent hardness.*

From the nature of the case the latter is much the more objectionable, as a mud deposit is readily removed. The cause of the deposit of the calcium sulphate, which forms the compact scale, is found in the insolubility of that salt at the high temperature attained in the boiler. The curve of solubility is seen to closely approach the zero line at a temperature of 150° C.

* The writer possesses some hard, dense, sulphate scale, of two inches in thickness, which was taken from the boilers of the steamer "Tybee."



CURVE OF SOLUBILITY OF CALCIUM SULPHATE.

As has been already said, page 365, the deposit of the carbonates held in solution by the temporarily hard water is caused by the escape of the solvent carbonic acid gas upon the temperature of the water reaching the boiling-point.

Should means other than the elevation of temperature be employed for the removal of the carbonic acid in solution, the precipitation of the dissolved carbonates would take place with equal certainty.

Thus many years ago Dr. Clark patented a process, which still bears his name, for removing the carbonic acid by the use of limewater, according to the equation

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O.$$

The calcium carbonate formed by the equation precipitates, and along with it also fall the calcium and magnesium carbonates originally held in solution in the water by the CO_2 thus destroyed.

In America the "Clark process" for softening temporarily hard waters is not very frequently resorted to, because our waters are commonly fairly soft, or else are permanently hard, a form of hardness for which the process is not suited.

In England, however, where chalk deposits are so plenty, this method of purification is more often seen, and even on so large a scale as that required for a city supply. At Southampton the water for 63,500 persons comes from a large well in the chalk, sunk in 1888; and it is softened by a "Clark process" plant of a capacity of 2,000,000 gallons daily. The water receives a charge of 10 per cent of its volume of lime water in a mixer and is then discharged into a softening cistern $38 \times 23 \times 3$ feet. After partial precipitation, the milky water passes to perforated filter-plates covered with cloth. The cost of this plant was about $50,000.

It provides 1½ tons of precipitate daily, and uses up ½ ton of lime for the purpose.*

For boiler purposes, the expensive filter presses would not be warranted, and simple settling-tanks should be substituted.

Care should be taken to avoid the introduction of more limewater than the reaction calls for, as a large excess would of itself cause a boiler-incrustation. The brown precipitate caused by pouring a solution of silver nitrate into limewater is a convenient indicator for use with the Clark process. As soon as the said brown precipitate appears, in a sample of the treated water, upon addition of a few drops of silver nitrate solution, the further introduction of lime water should cease.

The softening of permanently hard water may be accomplished by the addition of a solution of sodium carbonate, which causes a precipitation of insoluble calcium carbonate:

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4 .$$

At times this reaction and the resulting precipitation take place in settling-tanks or filter-plants, but more commonly the equation is fulfilled in the boiler itself, and the non-adhesive mud is afterwards blown off.

"In England the London & Northwestern Railway has a plant at Liverpool which removes the hardness from over 200,000 gallons of water daily, and it has also a plant at Camden Town, London. The Taff Vale Railway has a plant at Penarth Dock, near Cardiff, treating 50,000 gallons daily, and removing both the carbonates and sulphates of lime and magnesium. The cost per 1000 gallons softened is stated as about 1.26 cts. for the lime, soda, and alum used in the work."†

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* *Engineering*, March 11, 1892; see also *Engineering News*, April 16, 1892.

† This plant was described in *Proc. Inst. C. E.* vol. XCVII. p. 354.

Scale from sea-water consists mainly of calcium sulphate and magnesium hydrate; in fact, as Driffield has shown, magnesium occurs in these deposits as hydrate, although precipitated as carbonate, the conversion to the former being accomplished by the high temperature of the boiler.*

A very large number of boiler-scale " preventives " and " eradicators " have been placed upon the market which are peculiar for nothing, as Professor Chandler has well said, except their high price. Such as have any value whatever may be duplicated, at very little expense, out of quite common materials.

Unfortunately many of these preparations are perfectly inert, and not a few are positively harmful. In the latter class, for instance, the writer has found such material as acid sodium sulphate colored with logwood. Such a preparation acts upon metals with half the intensity of pure sulphuric acid, and its continued use must surely work injury to the boiler. A large class of these " preventives " aim not at the actual prevention of a deposit, but rather seek to alter its physical character.

Thus many of them are of a mucilaginous order, and their action is to so envelop the precipitating particles of mineral matter as to prevent their mutual adherence. A further action of such of the compounds as contain insoluble material like sawdust, is to provide separated nuclei, about which crystallization of the scale-forming salts may occur. In the first instance, such an increase in the viscosity of the water may follow as to cause serious frothing or " priming," and in the second there is additional danger of getting solid substances carried over into the moving parts. It is very questionable if as desirable results can be obtained by the

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* *J. Soc. Chem. Ind.* VI. 178.

employment of any of the "eradicators" as may be had by the use of ordinary sodium carbonate, or, still better, sodium fluoride.

This latter salt, first suggested by C. A. Doremus, when introduced into the boiler accomplishes its work of rendering the deposit non-crystalline and non-adhesive, without causing the water to assume an alkaline reaction, as is the case when sodium carbonate is employed.

The precipitate formed is always amorphous.*

R. Jones obtains the best results for preventing boiler-scale by the use of sodium carbonate. He uses enough to constantly maintain the water slightly alkaline after filtration, i.e., it gives a distinct red with phenol-phthalein, a solution of which the boiler attendant always has at hand. The boiler is blown off daily from the highest to the lowest water-level.†

Excellent results are also obtainable from the use of an iron-zinc couple, secured by attaching plates of zinc to the boiler-bracings. Protection of the iron results at the expense of the zinc plates.

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* *J. Am. Chem. Soc.* XV. 610.

† *Chem. News,* LXVII. 185.

APPENDIX.

APPENDIX A.

ANALYSES OF CITY WATER-SUPPLIES.

	Free Ammonia.	Albuminoid Ammonia.	Chlorine.	N as Nitrites	N as Nitrates	"Required Oxygen."	Total Residue.
Cambridge, Mass., average 1893...	.106	.202	5.8	.006	.285	4.043	66.6
Fitchburg, " " " ...	.001	.233	1.7	0	.033	2.870	26.8
Haverhill, " " " ...	.003	.182	2.4	0	.020	3.669	27.3
Lynn, " " " ...	.039	.214	5.5	.001	.054	5.102	36.1
Springfield, " " " ...	.009	.204	1.5	.001	.026	5.132	37.6
Boston, " " 1894...	.006	.319	4.1	.001	.106	6.295	46.4
Burlington, Vt. (Lake Champlain)..	.035	.140	0.7	0	trace	1.525	70.0
Poughkeepsie, N. Y. (Hudson River)	.050	.125	4.5	trace	trace	2.287	85.0
Washington, D. C. (Potomac)......	.050	.127	1.1	trace	.230	1.021	165.0
Richmond, Va. (James River).... .	.550	.150	1.17	trace	trace	1.654	105.0
Rock Island, Ill. (Mississippi R.)...	.025	.260	1.00	0	trace	6.000	140.0
New Orleans, La. (Mississippi R.)..	.040	.325	14.50	0	.080	5.724	340.0
Charleston, S. C. (Artesian well)...	.300	.040	130.00	.368	0	2.043	1170.0
Brooklyn, N. Y. (Ground-water)....	.001	.085	13.5	0	16.0	.....	64.0
Cincinnati, O. (Ohio River)........	.003	.108	14.0	.....	.26	.....	140
Philadelphia (Schuylkill River, average of 22)......................	.010	.100	......	0	.46	.....	133.4
Albany, N. Y. (Hudson River)......	.070	.200	2.5	trace	.082	5.7	......
Troy, N. Y. (Hudson River)........	.040	.150	2.5	0	.041	8.4	......
Cohoes, N. Y. (Mohawk River).....	.060	.210	4.0	.002	.246	3.55	......
New York, weekly average for 1894.	.012	.082	2.47	0	.258	.....	81.6
Extreme variations of same........	.005 to .025	.025 .175	2.04 2.89	0	.111 .489	.....	67. 97.
Paris (Vanne water, average for 1894)	...	.....	6	.....	2.22	.8	254

APPENDIX B.

DEATHS FROM TYPHOID FEVER, PER 10,000 INHABITANTS.

AVERAGES FOR PERIODS OF FIVE YEARS.

(Compiled by Dr. E. F. SMITH from official sources.)

	1846 to 1849	1850 to 1854	1855 to 1859	1860 to 1864	1865 to 1869	1870 to 1874	1875 to 1879	1880 to 1884
State of Michigan	......	......	......	......	......	4.5	2.7	3.2
State of Massachusetts	......	......	......	9.4	8.8	8.7	4.9	5.0
Boston, Mass	17.4	8.2	5.0	5.7	5.6	7.6	4.2	4.9
New York, N. Y	6.7	2.6	2.5	5.0	4.8	3.3	2.5	3.0
Brooklyn, N. Y	6.1	2.8	1.9	4.6	4.8	2.5	1.5	1.5
Baltimore, Md	......	......	......	7.4	7.8	8.0	6.1	4.8
Cincinnati, O	......	......	......	......	7.6	5.9	5.8	7.3
Chicago, Ill	......	10.2	6.8	6.9	7.9	8.4	4.1	6.8
St. Louis, Mo	......	......	......	......	10.4	7.2	3.5	4.3
New Orleans, La	13.8	8.3	9.6	11.5	5.7	3.8	2.5	2.7
England	......	10.0	9.0	8.5	9.3	6.6	4.3	3.0
London, Eng	11.5	9.9	8.5	9.5	8.4	4.9	3.3	2.7
Paris, France	......	......	......	......	5.5	10.8	6.2	9.9
Frankfort, Ger	......	8.1	9.1	5.0	6.1	7.1	2.6	1.4
Munich, Bav	......	12.5	25.4	16.2	13.0	15.3	8.6	2.7
Berlin, Ger	......	......	10.4	8.0	8.8	9.7	5.4	2.9
Breslau, Ger	......	......	......	......	11.3	6.4	4.3	3.3
Dantzic, Ger	......	......	......	......	10.6	7.0	2.5	1.5
Brussels, Bel	......	......	......	......	10.0	8.6	4.0	3.3

APPENDIX C.

Mr. J. W. Hill has collected the following statistics, showing deaths from typhoid fever, per 100,000 inhabitants:

AMERICA, 1894.

New York	17	Philadelphia, Pa	32
Brooklyn	15	Chicago, Ill	31
Newark, N. J	15	Baltimore, Md	48
Detroit, Mich	26	Washington, D. C	71
Cleveland, O	27	Pittsburg, Pa	56
Boston, Mass	28	Buffalo, N. Y	36
Dayton, O	20	San Francisco, Cal	35
Milwaukee, Wis.	26	Cincinnati, O	50
New Orleans, La	28	Louisville, Ky	72
Toronto, Can	17	Providence, R. I	47
Lawrence, Mass	30	Jersey City, N. J	76
St. Louis, Mo	31	Lowell, Mass	55

EUROPE, 1893.

London, Eng	16	Munich	15
Manchester, Eng	25	Trieste	17
Edinburgh, Scot	14	Vienna, Aus	7
Glasgow, Scot	20	Budapest, Hun	15
Paris, France	25	Brussels, Bel	27
Amsterdam, Hol	16	Venice, It	26
Rotterdam, Hol	5	Rome, It	34
Hague, Hol	2	Turin, It	29
Copenhagen, Den	9	Liverpool, Eng	53
Stockholm, Swe	8	Dublin, Ire	87
Christiania, Nor	6	St. Petersburg, Rus	51
Berlin, Ger	9	Moscow, Rus	40
Hamburg, Ger	18	Prague, Boh	36
Dresden, Ger	4½	Milan, It	62
Breslau, Ger	10		

APPENDIX D.

ABSTRACT OF A MEMORIAL TO CONGRESS, PRESENTED BY THE "AMERICAN WATER-WORKS ASSOCIATION," PRAYING FOR A NATIONAL LAW TO RESTRICT POLLUTION OF STREAMS FROM WHICH WATER-SUPPLIES OF CITIES ARE DRAWN.

Whereas, It is universally conceded that "public health is public wealth," and hence it appears your bounden duty to carefully protect it; and,

Whereas, Pure water, on the one hand, is known to be the prime essential of sound individual and public health, while polluted water, on the other hand, is likewise known to be the cause, direct or indirect, of over one half the ailments that afflict, weaken, or totally destroy human life; and,

Whereas, It appears from the last census that not less than one hundred thousand (100,000) human lives are lost annually in these United States by death resulting from preventable diseases—diseases caused more or less directly by the use of polluted water, or, more strictly speaking, diluted sewage—*one hundred thousand* (100,000) souls each year, especially from among the young and more active of the population—equal in wage-earning capacity, at the very low estimate of one dollar each per day, to $100,000 per day, $700,000 per week, $36,400,000 per year, a net loss of active, intelligent, and self-investing wealth, to say nothing of interested and useful citizenship and other inherent virtues and qualities which raise this class of wealth incalculably above gold, silver, bonds, and brutes; nothing of the cost of rearing and educating infants and children to the age of useful activity; nothing about the cost of medical and other attendance on the victims of death during their sickness;

nothing of the cost of their burial, and of the sorrows and disappointments inflicted upon those who survive; and,

Whereas, Said preventable diseases—most of which are epidemic—are spread and sustained in their virulence and destructive energy by the general practice of carelessly and selfishly sewering excrements and other disease-breeding refuse into the ground-water courses, and into the streams and lakes which constitute the natural sources of water-supply for the people; and,

Whereas, It is the general practice to dump street sweepings, backyard rubbish, manure, all kinds of household and barn refuse, poisoned and other dead animals on the banks of streams for the "high waters to wash away," and the unsanitary and dangerous results prove such that, even in the state of Massachusetts (which has always been far in advance of any other state of the Union in its sanitary regulations of sources of water-supply and of sewer systems), the Board of Health and the Boston Water Board felt constrained to obtain the passage, by the legislature of 1890, of a bill whereby the Board of Health has been granted authority to prohibit the depositing of manure, excrements, garbage, sewage, or any other polluting matter within one hundred feet of the high-water mark of any stream or body of water used as a source of water-supply; and

Whereas, But few of the rivers and lakes thus polluted and made sources of discomfort, disease, and death to the people, instead of means of comfort and health—are wholly within the limits of any individual State, and as most all our rivers run into, along, or through from two to ten of the States, and thus render it impracticable for the States individually to bring relief, while it is perfectly practicable and constitutional for, and most needful that, the Federal Government should, with the help and co-operation of the States, bring due relief; and

Whereas, It plainly appears that just and equitable general laws governing these important relations, with a competent Board of National Water-Supply and Sewerage Commissioners, separate from party political influences and empowered and provided with sufficient authority and ample discretionary powers, as well as the means necessary to faithfully administer them—are urgently needed; and

Whereas, Our national attractions and resources are so great, numerous, and widespread, and our commerce with other nations so vast and varied, and our means of intercourse with the whole world so rapid and extended, as to seriously and constantly expose our ever-busy people to epidemic diseases of foreign origin, such as Asiatic cholera, which has cost the Old World more human lives than all the wars from the siege of Jerusalem to the fall of Paris, and which propagates itself by means of germs that breed or split and develop to full energy with the exceeding rapidity of scores per minute, and trillions per hour, and spreads mainly through the water that people drink, and ravages most fiercely where filth in drinking-water most abounds; and

Whereas, All our streams, lakes, and underground water-beds, which are the natural sources of water-supply for the people, are utilized throughout the land more or less as common sewers by cities, towns, villages, isolated households, and various industries, thus rendering such streams, lakes, and ground water beds—by the presence of excrements, putrefying animal and vegetable matter, and other filth they contain—most effective breeding and spreading means, not alone of Asiatic cholera, but also of typhoid fever, diphtheria, *cholera morbus*, and various other diseases no less destructive of human comfort, health, strength, and life, and, likewise, paralyzing to education, industry, and commerce; therefore,

Resolved, That we, the American Water-works Association, a body composed of, etc., etc., most earnestly pray

that you will grant this deeply important matter the prompt and careful consideration and attention it requires, and that you will be pleased to speedily devise the ways and means by which the people may soon be saved from such unnecessary and oppressive burdens and sorrows, and the nation from such enormous loss.

APPENDIX E.

WEIGELT records the following observations of the effects upon fish of waters contaminated with products of industrial waste: *

Contained in One Million Parts of Water.	Kind of Fish Used.	Observations.
70 slaked lime, $Ca(OH)_2$..........	Trout.	Dead in 26 minutes.
1000 soda, $Na_2CO_3 . 10H_2O$......	"	After 3 minutes, restless.
0.5 chloride of lime, $CaCl_2O$......	"	Dead in 3 hours.
100 hydrochloric acid, HCl... ...	"	On its side in 4 minutes.
100 sulphuric acid, H_2SO_4.... ...	"	On its side at once.
50 ammonia, NH_3..............	"	Dead in 47 minutes.
100 sodic arsenate $Na_2AsO_4 . 12H_2O$	"	Strong effect.
50 mercuric chloride, $HgCl_2$......	"	Dead in 54 minutes.
1000 calcium chloride, $CaCl_2$.. ...	"	An effect in 2 hours.
100 green vitriol, $FeSO_4 . 7H_2O$...	"	Dead in 5 hours.
50 " " " ...	"	No effect in 16 hours.
1000 iron chloride, Fe_2Cl_6........	"	On its side in 3 minutes.
1000 manganese chloride, $MnCl_2$..	"	Speedy restlessness.
5 carbolic acid, C_6H_5OH...	"	Restless in 15 minutes.
1000 soap (unfiltered)............	Salmon.	Dead in $1\frac{1}{2}$ hours.
1000 soap (filtered)...............	"	No effect.

* "Das Wasser," Fischer, 52.

APPENDIX F.

WATER FOR INDUSTRIAL PURPOSES.

BREWING.—The water should be very free from all decomposable organic matter; and from tannic acid infusions, such as might be obtained from a forest floor.

A good deep-seated water will serve the best. Although a soft water does well for porter and dark beers, because of its being a better solvent for coloring matter, yet for general purposes a certain amount of "permanent" hardness is preferable. "For pale ale there must be not less than 300 to 400 parts of $Ca\ SO_4$ per million."

Those ingredients to be especially avoided are: Iron salts, sulphides, and high chlorides, especially magnesium chloride.

The following analysis, by Stolba, is of the water used for the celebrated Pilsner beer: *

Calcium sulphate	67 per million
Calcium carbonate	40 " "
Magnesium carbonate	33 " "
Iron carbonate	trace " "
Magnesium chloride	0 " "
Silica	22 " "
Organic material	trace " "
Sodium chloride	10 " "
Potassium chloride	trace " "
	172 " "

DYEING AND BLEACHING.—The water should be clear and soft. For the few dyes which are found to act better with a somewhat hard water, the hardness may be artificially created as required. Iron salts are especially objectionable.

* "Das Wasser," Fischer, 45.

They modify some colors, and leave stains upon light goods, particularly after contact with alkaline compounds.

The same objections hold good for salts of manganese. Hard waters decompose soap (page 365), often modify colors, and deposit insoluble calcium salts in the fibre.

A uniform water, distinguished from one of seasonal variation, is especially desirable, to permit of matching shades of color.

PAPER.—Clear, clean water is required, free from iron, which causes rust spots.

SUGAR.—Nitrates are especially objectionable, as they interfere with the crystallization of the sugar.

APPENDIX G.

THE following definition of liquids which should be deemed polluting and inadmissible into a stream was formulated by the Rivers Pollution Commission of Great Britain (1886):

(*a*) Any liquid which has not been subjected to perfect quiet in subsidence ponds of sufficient size for a period of at least six hours, or which, having been so subjected to subsidence, contains in suspension more than one part by weight of dry organic matter in 100,000 parts by weight of the liquid, or which, not having been so subjected to subsidence, contains in suspension more than three parts by weight of dry mineral matter, or one part by weight of dry organic matter in 100,000 parts by weight of the liquid.

(*b*) Any liquid containing, in solution, more than two parts by weight of organic carbon or 0.3 part by weight of organic nitrogen in 100,000 parts by weight.

(*c*) Any liquid which shall exhibit by daylight a distinct color when a stratum of it one inch deep is placed in a white porcelain or earthenware vessel.

(*d*) Any liquid which contains in solution, in 100,000 parts, by weight, more than two parts by weight of any metal except calcium, magnesium, potassium, or sodium.

(*e*) Any liquid which in 100,000 parts by weight contains, whether in solution or suspension, in chemical combination or otherwise, more than 0.05 part by weight of metallic arsenic.

(*f*) Any liquid which, after acidification with sulphuric acid, contains, in 100,000 parts, by weight, more than one part by weight of free chlorine.

(*g*) Any liquid which contains, in 100,000 parts by weight, more than one part by weight of sulphur, in the condition of either sulphuretted hydrogen or a soluble sulphuret.

(*h*) Any liquid possessing an acidity greater than that which is produced by adding two parts by weight of real muriatic acid to 1000 parts by weight of distilled water.

(*i*) Any liquid possessing an alkalinity greater than that which is produced by adding one part by weight of dry caustic soda to 1000 parts by weight of distilled water.

(*k*) Any liquid exhibiting a film of petroleum or hydro-carbon upon its surface, or containing in suspension, in 100,000 parts, more than 0.5 part of such oil.

To these standards was attached the proviso, that "no effluent water shall be deemed polluting if it be not more contaminated with any of the above-named polluting ingredients than the stream or river into which it is discharged."

APPENDIX H.

THE USE OF SEA-WATER FOR STREET-WATERING, SEWER-FLUSHING, AND OTHER PURPOSES.

Sundry theoretical objections having been raised to the use of sea-water for such purposes, the following letters were obtained from officials of English sea-coast towns, and were embodied in a paper, by J. W. Cockrill, abstracted in *Engineering News*, Nov. 17, 1892.

Birkenhead.—"One spread of salt water on the surface of a street or road is equal to about three spreads of fresh water, as the latter under the heat of the sun evaporates, whereas the salt water leaves a crust on the surface and keeps down the dust for a considerable time. We have not yet flushed our sewers with salt water."

Hastings.—"Sea-water has been used in this town for some years for street-watering and sewer-flushing, and no inconvenience has been found to arise. There is, perhaps, rather more mud on the roads during the autumn, but, on the whole, I believe that sea-water has a good sanitary effect on both roads and sewers."

Worthing.—"Many of our streets are watered with sea-water, and have been for years. The effect upon roads is to bind them together almost like cement; dust is never seen on these roads when dry, and sea-water keeps damp at least as long again as fresh water. Such an argument as sea-water acting upon sewage so as to make it offensive is simply absurd."

Eastbourne.—"We thought of using sea-water some years ago, but as there was a general objection to it we gave it up. From what I have seen of its use, my opinion is that it materially assists the solidifying of a road."

Brighton.—"We do not use sea-water for street-watering, but we use it for flushing our main intersecting sewer, and if used in sufficient volume it is not offensive."

Blackpool.—"This corporation has used sea-water for street-watering and sewer-flushing for some time, and I find no complaints arise whatever, but sea-water makes sett-paving slippery."

Ryde.—"I can state confidently, after thirty years' experience in the use of salt water for watering roads, that so far from deteriorating macadamized roads, it hardens the surface; so much so, that during the recent dry summer we found that in streets with a gradient of 1 in 12, when it was necessary to water a second time in the day, we were compelled to use fresh water, otherwise the streets would have become too slippery. Doubtless, after a long course of salt water on a level road, when rain first comes, the surface will be a little dirtier than if fresh water had been used. We find it pays to use salt water when a load of water costs twice as much as fresh. With reference to flushing sewers, I have had very little experience."

Rhyl.—"Sea-water will not injuriously affect macadamized roads, but have a good effect."

Torquay.—"I have used sea-water for street-watering upon macadamized roads for several years, and do not find any inconvenience; but if there is any difference between salt and fresh water, I think the salt water is preferable. I do not use salt water for flushing, except very rarely in the low level, and then I do not find any smell more offensive than at other times."

Margate.—"Had no special means of raising salt water, and so gave it up; when used, one load went as far as three loads of fresh water."

Plymouth.—"All the low levels are watered with it; con-

sider that two loads of fresh water are not equal to one of salt."

South Shields.—" One load of salt water equals four loads of fresh."

Tynemouth.—" Has a very good effect upon street surface, as it hardens the surface of macadamized roads; we use it for watering, flushing, and baths."

Barrow-in-Furness.—" Use salt water for street-watering; when fresh water used it took twice the quantity."

Ilfracombe.—" Used sea-water formerly, and contemplate doing so again. It retains its effect twice as long as fresh water, and it is very binding."

In addition to the foregoing, the following opinion of Mr. H. P. Boulnois may be quoted: " Watering the streets with sea-water should be adopted wherever it is feasible, as it not only gives a delightful freshness to the air, but it also causes the surface of the street to maintain its humidity for a longer period than when fresh water is used."

" The general results may be stated as follows: Since the construction of the works the consumption of water for street-watering has been annually less than 5,000,000 gallons at 5 cents per 1000 gallons, instead of 7,000,000 gallons at 24 cents per 1000 gallons, as before."

" Used in sewer-flushing, salt water has cleaned them thoroughly, and after five years' experience no nuisance of any kind has followed. Its effect in the Yarmouth sewers has been to reduce and almost prevent the generation and accumulation of sewer-gas. Sewers can now be entered at once on the removal of the manhole cover; which was not the case before. An 18-inch pipe sewer on a gradient of 1 in 300 was formerly constantly clogged by deposits; it is now kept thoroughly clean by two flushes per day from a 3000-gallon tank, which fills the sewer two thirds full. There are no deposits of any sort in the sewers, except in several of

the larger ones, and there it has been reduced one half since salt water has been used. As to the effect of salt water on iron, the author says that the siphons are of galvanized sheet-iron only, but they have required no repairs since they were put in. As to the sulphates in sea-water, no evil effects are traceable; the town possesses no manufactories and no acids are discharged into the sewers."

"The salt water has never been used for extinguishing fires, though it is available if needed. The author does not recommend it for this purpose, as he considers that a dwelling would not be habitable after its walls had been saturated with sea-water. It is used for private baths with satisfaction to the users."

INDEX.

ERRATA.

Page 179. Free Am. (Albany). *For* 0.6000 *read* 0.0600
193, second line below dash: *for* seasonable *read* seasonal
194, last line: *omit* Hoboken
207, sixth line from bottom: *for* inclined *read* unlined
217, tenth line from top: *for* seasonable *read* seasonal
371, fifteenth line: *for* page 206 *read* page 205
390, fifth line from bottom: *for* 1.3 m.g. *read* .13 m.g.
415, footnote: *for* 195 *read* 194

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